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# Effect of high latitude on the variability of human event-related brain potentials

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# EFFECT OF HIGH LATITUDE ON THE VARIABILITY OF HUMAN EVENT-RELATED BRAIN POTENTIALS

A

DISSERTATION

Presented to the Faculty

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Interdisciplinary Studies

Neuroscience

By

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Fairbanks, Alaska

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The dissertation by Anita M. Bush

EFFECTS OF HIGH LATITUDE ON THE VARIABILITY OF EVENT-RELATED BRAIN POTENTIALS IN HUMANS

is accepted in its present form
by the advisory committee:

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In Claude Bernard's words "Art is I, Science is we." So, too, is the work behind this dissertation. Many people contributed valuable support and encouragement and deserve special recognition and thanks.

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ABSTRACT OF THE DISSERTATION

# Effect of High Latitude on the Variability of Event-Related Brain Potentials of Humans

by

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Doctor of Philosophy in Neuroscience
University of Alaska Fairbanks, 1993
Professor Charles R. Geist, chairperson

A team of European researchers (Anderson, Chambers, Myhre, Nicholson, & Stone, 1984) have reported seasonal changes in the human electroencephalogram, EEG, at 69 degrees north latitude. One team (Deldin, Duncan, & Miller, 1989a, 1989b) from the North American mid-latitudes, using an experimental component of the EEG known as an event-related potential, ERP, and recording from a large number of single-trial subjects, report changes associated with ambient light. However, such changes in the ERP have not been reported at high latitude or by longitudinal methods.

The literature of ERP research contains very few longitudinal studies, and none under natural conditions of pronounced photoperiodicity such as occurs at high latitude. The purpose of this dissertation is to begin to fill that knowledge gap.

One hundred and twelve human subjects, males and females, ages 14 to 81 years, living in Fairbanks, Alaska (64 degrees north, 141 minutes west) participated in single-trial event-related potential testing, in both auditory and visual oddball detection paradigms, to address issues of validity of the ERP measure and reliability of the results obtained in samples of normal subjects from a subarctic population. Subsequently, eight normal humans, four females and four males, ages 9-46 years, participated in event-related testing, using both the auditory and visual techniques, every month for twelve consecutive calendar months. The eight longitudinally-studied subjects were residents of the subarctic where testing occurred.

For the purposes of this dissertation only the amplitude and latency of the P3 portion of the auditory and visual ERPs, recorded as a response to an attended stimulus, are formally analyzed. The 12-month variability of the amplitude and latency of the N1, P2, and N4, both auditory and visual, for attended and ignored stimuli, are presented graphically in Appendix B. Independent variables in the longitudinal study included: age, estimated cranial volume, length of last sleep epoch, subjective wakefulness, total

magnetic field strength in the recording cubicle, ambient geomagnetic field, and ambient photoperiod.

Longitudinal ERP data distribution was observed to satisfy criteria for normality. The conservative technique of the general linear model analysis of variance, for ordered repeated measures, was used and an effect of month was demonstrated for both amplitude and latency. Likewise, a significant month-by-sensory mode interraction was observed. The ERP data were evaluated using the principal components method of factor analysis to determine the factor weights of the independent variables. Variables unique to each subject (e.g., age, cranial volume, and length of last sleep) were more heavily weighted in the first factor than were common environmental factors. The environmental descriptors of the geomagnetic field and photoperiod became weighted in the second factor. Of these, photoperiod was weighted less as compared to the descriptors of the earth's geomagnetic activity. Ambient geomagnetic field strength on the day prior to ERP testing weighted the PCA factors more heavily than did field strength in the recording cubicle at the time of testing.

Following PCA analysis, the two most heavily weighted environmental variables, geomagnetic field and photoperiod, were separately investigated to determine if the significant monthly variability detected in the longitudinal ERP data could be interpreted as a response to naturally-occurring environmental variation. No seasonal variability in ERP

characteristics was detected when using a photoperiod-based definition of season. However, variability in auditory P3 amplitude was observed when using categories based on geomagnetic criteria.

This investigation of ERP variability over time, in normal humans living at high latitude, further emphasizes that event-related brain potentials are highly variable phenomena and that the observed variability may be related to a diversity of physiological, psychological, and/or environmental factors.

# INTRODUCTION

## Philosophical and Theoretical Bases

The ideal beginning would be to present theoretically relevant neuroscience. The problem is that neuroscience is in the very early stages of theory development, hence judgements about what is or is not theoretically relevant are both premature and naive. As yet, neuroscience research in general, and event-related potential research in particular, have no robust, commanding, widely adopted theory against which to assess the theoretical importance of data. In contrast to physics (the universal gas law, for example) a large-scale theory of brain function (a universal neuron law, for instance) does not currently exist. This means only that we lack a governing paradigm, it does not mean that there are no theories (Churchland, 1986).

Today, all researchers studying the brain are called neuroscientists. Dorland's (Friehl, 1974) credits the Greeks for the root word neuron which the Oxford American Dictionary (Ehrlich, Flexner, Carruth, & Hawkins, 1980) defines as pertaining to the nervous system. That science

pertaining to the nervous system is the systematic observation of natural phenomena for the purpose of discovering laws governing those phenomena (Friehl, 1974). Neuroscience, therefore, is natural philosophy.

The essence of natural philosophy (R. Krecji, personal communication, 1991) consists of three statements:

1) a Nature exists around us.

2) that Nature is governed by laws.

3) those laws can be discovered.

Philosophically, most neuroscientists today are monists and ascribe to the belief that there is but one ultimate substance, matter, and that the workings of the mind (e.g., seasonal depression, addictions, biological rhythms) can be explained by physiochemical processes. Allport (1986) sums up this philosophy as "there seem to be no very compelling reasons to suggest that matter cannot account for mind" (pg. 49). And George Page, narrator of the PBS-TV series The Mind (WNET, 1990) opened the first episode by stating "[t]he mind is what the brain does." The philosophy of science (R. Krecji, personal communication, 1991) assumes that all minds operate in similar ways, ergo all brains operate in similar ways.

Despite not having an articulated governing paradigm, contemporary neuroscience is strongly influenced by two traditional foci for experimental and theoretical investigations.

## The Brain Hypothesis

The brain hypothesis (Kolb & Whishaw, 1990) is the idea that the brain is the source of behavior, whether the behavior is salmon migration, chimpanzee gestures, ground squirrel hibernation, or human performance. If we are to understand an organism's behaviors, we must understand its brain.

The investigational techniques such as electroencephalography in general, and event-related potential recordings in particular, are generally employed by neuroscientists who approach the study of phenomena in terms of the brain hypothesis.

## The Neuron Hypothesis

The neuron hypothesis (Kolb & Whishaw, 1990) is the idea that the unit of brain structure and function is the neuron. Behavior is commenced, modulated, and terminated by alterations in neuronal membrane potentials which can be described by physiochemical processes.

Investigational techniques such as neuronal membrane patch-clamp recording are used by neuroscientists who approach the study of phenomena in terms of the neuron hypothesis.

Event-Related Potential Application. Halliday (1984) in addressing the EPIC VI meeting, summarized the challenge to neuroscientists investigating event-related potentials.

"We are rich in experimental data but poor in

theory. It is time for what might be called 'bridled speculation'" (pg. 764).

Picton (1984) identified two theory needs in ERP research. One is a theory of how the brain acts to produce human behavior and subjective experience. A second is a theory of how the ERPs relate to different processes in the brain.

The field of event-related potential research still lacks a generally agreed upon conceptualization of the phenomena studied. This theoretical void exists, in my opinion, due to the current limitations of our investigative tools, the research climate in which those tools are used, and the ethical constraints necessitated when both are applied to human subjects.

## The Current Investigation's Contribution to Knowledge

Biological organisms, including humans, display a wide range of variable physiological processes. Certain processes of human physiology are known to exhibit rhythmic patterns in their normal variability (Gibbons, 1991; Moore-Ede, Sulzman, & Fuller, 1982).

Ultradian Rhythms. These processes complete one cycle in a period of less than 24 hours. For example: sleep-stage (about 90 minutes), basic rest-activity pattern (about 90 minutes), respiratory cycle (about 6 seconds), cardiac cycle (about 1 second), and the EEG rhythms (delta, theta, alpha, beta) which complete their cycles in less than one second.

Circadian Rhythms. These processes complete one cycle in a period of approximately 24 hours. For example: our core temperature varies about 0.5 degrees Centigrade over the course of 24 hours, likewise, arterial blood pressure exhibits a fluctuation of as much as 20%, leukocyte count fluctuates as much as 50%, serum cortisol, serotonin, melatonin and norepinephrine all manifest an acrophase and nadir within about a 24-hour period.

Infradian Rhythms. These processes complete one cycle in a period longer than 24 hours. For example: the normal menstrual processes complete their cycle about every 28-30 days, and some humans exhibit a seasonally recurring mood disorder.

In particular, seasonal affective disorder, SAD, in humans manifests as a cluster of physiological and psychological symptoms, the precise nature and mechanisms of which are somewhat disputed (Blehar, & Lewy, 1990; Gibbons, 1991; Lewy, Sack, & Singer, 1984, 1985; Rosenthal, Sack, Gillin, Lewy, Goodwin, Mueller, Newson, & Wehr, 1984; Rosenthal, & Wehr, 1987). The SAD criteria generally accepted for inclusion in the Diagnostic and Statistical Manual of Mental Disorders, DSM-III-R, include "a regular temporal relationship between the onset of an episode...and a particular 60-day period of the year; full remissions also occur within a particular 60-day period of the year" (American Psychiatric Association, 1987, pg. 224). An episode, as used here, is characterized by symptoms of

bipolar disorder, and generally includes changes in appetite, mood, and energy (American Psychiatric Association, 1987; Gibbons, 1991).

SAD symptoms have been investigated for their relationship to the duration and intensity of light, and although SAD has not been proven to be a circadian rhythm disorder, SAD symptoms and their treatment with bright light are generally recognized by the psychiatric community (Gibbons, 1991). SAD phenomena have been investigated in the subarctic population of Fairbanks, Alaska (Hellekson, 1989; Hellekson, & Rosenthal, 1987). Peak incidence of SAD symptoms was observed for March. In this locale, March is characterized by increasing amounts of daylight, coming out of the mid-winter photoperiod minimum and approaching the vernal equinox level of 12 hours.

A Norwegian study (Anderson, et al., 1984) conducted at 69 degrees north latitude, reported human EEG changes related to season. A few years after this report, in the course of investigating SAD symptom response to bright light therapy, an experimental component of the EEG, the event-related potential, ERP, was employed experimentally (Duncan, & Rosenthal, 1986). The researchers attempted to quantitatively associate SAD symptom remission with measured changes in ERP characteristics.

The attempt to quantify remission of SAD symptoms with ERP changes is perhaps premature. These potentials are

highly variable phenomena and the literature of ERP research has yet to address such issues as:

1) how much variability in ERP recordings can be expected over time in normal (SAD symptom free) human subjects.

2) how much of the normal ERP variability is due to changing environmental factors such as photoperiod.

3) whether the variability of ERPs recorded from SAD subjects differs from the variability observed in asymptomatic subjects under conditions of changing ambient light.

The purpose of this disseration is to examine the effects of naturally-occurring high-latitude conditions on the normal variability of ERPs recorded from normal (SAD symptom free) humans. As further investigations from lower latitudes and using SAD subjects become available in the future, the nature of an infradian rhythm in ERP variability might eventually be identified, and a clarification of the extent of ERP changes which accompany SAD symptoms and their remission may one day be elucidated.

## Limitations and Key Assumptions

This dissertation and the work preceeding it are the product of an interdisciplinary program of study. The common, relevant perspectives of the composite disciplines are included. Necessarily, neither an exclusive nor

exhaustive single-discipline viewpoint can be reasonably or satisfactorily addressed.

Furthermore, this longitudinal ERP study at high latitude is the first work of its kind. The very nature of early investigation lends itself to the overcollection of data, particularly so when recording event-related potentials on human subjects. Therefore, only the P3 portion of the waveform, recorded during attention to a target stimulus, and which has a substantial body of literature, is considered in the formal analyses and discussions. The variability of the remaining components, measured over the 12-month collection period, are presented in simple graphical form in the appendix without further comment in the dissertation proper.

It is worth stating at the outset that event-related potential recordings are an experimental tool. The precise cerebral origins of the various named components remain to be conclusively identified. And while certain subject characteristics, both physiological and psychological, have been reported to influence ERP variability, the effects of environmental factors have yet to be addressed. Therefore, the picture of ERP variability under natural high latitude conditions is painted in necessarily broad strokes.

# REVIEW OF THE LITERATURE

## State-of-the-art: Event-Related Potentials

Almost ten years ago Norman Loveless, then a psychologist at the University of Dundee Scotland, declared that "[a]ny attempt to provide a straightforward and coherent account of ERP research misrepresents the actual state of knowledge" (Loveless, 1983, pg. 88). Though the field has progressed in terms of improving techniques and technology, the basic questions of what is an event-related potential, what functional processes do the ERPs represent, and for what are the techniques useful, remain largely unanswered.

Part of the challenge in this regard is finding an academic home in which to pursue the intriguing questions in ERP research. In Picton's opinion "[t]he use of event-related potentials is quite distinct from other approaches to studying the brain...[ERP research is different] from either psychology or physiology ...[ERP researchers] have the advantage of providing a novel perspective on brain function, but the disadvantage of being often disowned by our parent disciplines" (Picton, 1984, pg. 753).

While it is true that researchers studying event-related brain potentials have amassed an impressive mound of data since the P300 event-related potential was discovered (Sutton, Braren, Zubin, & John, 1965), it is also true that many important questions about these fascinating potentials remain unanswered. Donchin (1984) describes the two basic questions in ERP research as: 1) where in the brain is the processor that is generating a particular component of the scalp-recorded electrical field, and 2) what is that processor doing.

From a historical perspective (Petsche, Pockberger, & Rappelsberger, 1984), the English physiologist Richard Caton is credited with demonstrating in 1875 that the living brain produces electric oscillations; however another 50 years of work were required before the German psychiatrist Hans Berger successfully recorded the potential oscillations from the intact scalp of man in 1925. Another forty years of work were required before Sutton et al. (1965) identified event-related potentials in scalp recordings. Now, 118 years after Caton, as the end of the third decade of ERP research approaches, the answers to Donchin's (1984) two basic questions remain unanswered. A host of other, perhaps more practical, matters such as: how many components are there, how shall they be named, and is positive up or down, are also unresolved.

In the proceedings of the EPIC VI conference, where the 20-year state of ERP research was assessed, one of the P300

ERP discoverers, Sutton, identified that "[t]here appear to be many more components in the scalp-recorded event-related potential than we thought there were only a few years ago" (Sutton, & Ruchkin, 1984, pg. 2). Indeed, in primary papers of the past 10 years, it would appear that every little squiggle of the recording pen is being named.

Since this dissertation must be limited in some fashion to be both readable and useful, discussion henceforth is deliberately limited to what is generally termed the P3 or P300.

Another issue ERP researchers have yet to decide: how shall we name the components being described? By convention, the net electrical polarity of a component is described as either positive, abbreviated P, or negative, abbreviated N (Sutton, & Ruchkin, 1984). The ERP literature contains two numbering methods for the components: an ordinal scale (1,2,3,4....) and a time-based (50, 190, 300... milliseconds) scheme. The time-based identification is common to the early literature while the ordinal scale identification is more common to later works as it has become clear that the latency, or timing, of a component can be altered by a variety of factors (Sutton, & Ruchkin, 1984), e.g. a P280 may be the very same component as a P330 under different conditions. Thus, this dissertation is being limited to the third positive complex usually occurring at about 300 milliseconds in the recording (P3=P300).

One might guess that a component's polarity would be a rather straightforward descriptor; one would guess wrongly. All who have spent any time at all recording event-related potentials would attest to the fact that negative components may be observed on the positive side of the baseline, and vice versa, and that this problem stems in no small part from how one defines the baseline. Even when the baseline is defined separately for the individual components, recording displacement due to component overlap can put a negative component on the positive side of the baseline (Sutton, & Ruchkin, 1984). Therefore, polarity simply describes the movement of a component towards its peak, which is either positive-going or negative-going.

Where one defines baseline also has implications for amplitude results. There are two common methods for measuring amplitude in the ERP literature. One method measures amplitude from a defined baseline. The other measures amplitude as the absolute amount of deviation from peak-to-trough. The two methods give different results (see experiment one). In the present investigation, the P3 amplitude is measured from a defined prestimulus baseline.

A picture of the waveform might save a thousand words of description, but it might not. How shall this positivity be graphically represented, up or down? The ERP literature contains illustrative waveforms which depict positive polarity as going in either direction. Such inconsistencies, however, do not particularly disturb Adolf

Pfefferbaum, a psychiatrist at the Veteran's Administration Medical Center in Palo Alto, California. In his own words (Pfefferbaum, 1984): "...I do not feel uneasy in a field that is fraught with questions about what is real and beset with decisions about whether positive is up or down. Any science that does not know up from down is one where a psychiatrist can feel completely at home" (pg. 764). In the present investigation, positive is up.

As can be seen, the field of event-related potential research is in its infancy, very little is known conclusively about these waveforms, and much basic research remains to be done before event-related potential recording techniques can be removed from the experimental laboratory for use in clinical settings where decisions about individuals are made. The interpretations unavoidably fall too far short of metaphysical certitude.

This does not mean that the past 28 years of investigating event-related potentials have been fruitless, or that researchers investigating ERPs are ignorant of what remains to be accomplished. Donchin (1984) attempts to articulate a sentiment shared by many who study event-related brain potentials, that is "[w]e are often frustrated when we cannot determine a single question that can be answered by a simple experiment. We have to accept the fact that we must use converging operations and approach our goals from a variety of views" (pg. 765). And with that acceptance has come some progress toward answering the two

basic questions: where is the processor and what is it doing.

## Cerebral Origins

Though fairly reliable changes in the event-related potentials are observed in relation to certain cognitive variables and neurological status, functional interpretation remains limited by not knowing the generator source.

The Brain Research Institute of UCLA has been vigorously pursuing this challenge (Harrison, Buchwald, Kaga, Woolf, & Butcher, 1988) and catalogs the variety of techniques which have been used to examine the proposed generators: topographical mapping and depth electrodes in the frontal cortex (Courchesne, 1978), topographical mapping and depth electrodes in the centro-parietal cortex (Vaughan, & Ritter, 1970), electromagnetic recordings of the temporal cortex (Richer, Johnson, & Beatty, 1983), and recording from subjects with well-defined lesions (Stapleton, 1985). Of these techniques, depth recording has provided the most direct evidence suggesting a strong association of limbic activity with event-related potential characteristics.

Depth Electrodes. As an example, one UCLA team (Halgren, et al., 1980) has reported strong evidence suggesting the limbic structures of hippocampus and amygdala as likely sources of endogenous potentials in humans. In their work,

six adult volunteers, of reportedly normal intelligence and personality, were being assessed with implanted electrodes to locate epileptic foci for possible surgical removal. A total of 41 electrodes were implanted among them: 13 in the hippocampal gyrus, 20 in the hippocampus, and 8 in the amygdala. After recovering from implantation, the six subjects participated in simple auditory and visual attentional discrimination tasks, i.e., to silently count the number of times an oddball stimulus occurs, while electrical activity was recorded from the electrodes. The results included waveforms remarkably similar to what have been recorded from the scalp surface in similar sensory discrimination tasks.

Aside from the obvious argument that epileptic persons exhibit pathologically-altered brain electrical activity, what Halgren's et al., (1980) results do not indicate (since no concommitant scalp-surface recording was performed) whether the depth and surface recordings are simply associated, or whether some component of the scalp-recorded potentials is, in fact, a passively volume-conducted reflection of the limbic activity. The ability of any particular brain structure to generate electrical fields which are detectable on the surface depends not only upon that structure's location, size, and activity, but also upon the geometry of its cells (Nunez, 1981; Wood, Allison, Goff, Williamson, & Spencer, 1980). In these respects the hippocampus is a potential candidate for a volume-conducting

source generator given its aligned, long apical dendrites of the pyramidal cells.

Most potentials recorded at the scalp consist primarily of synaptic potentials since action-potentials do not volume-conduct over large distances (Wood, et al., 1980). Potentials that are volume-conducted to the surface of the brain will be further affected by the high resistance of the skull (Nunez, 1981). It has been suggested (Martin, Barajs, Fernandez, & Torres, 1988; Picton, Stuss, Champagne, & Nelson, 1984) that perhaps the characteristic differences noted between the genders might simply be due to the fact that males, who are generally larger than females, have thicker skulls. Perhaps some of the age-related differences, particularly when comparing the developmentally young with an adult, could be, in some part, attributed to volume-conduction differences since the head size of a child would be expected to be smaller than the head size of an adult.

Therefore, in the present investigation, a non-invasive estimate of the subject's cranial volume is included as an independent variable, as well as the subject's age. Clarifying the volume question is important in order to better understand how fields produced by a sub-surface generator are distributed on the body-surface (Schmidt, & Pilkington, 1991; Stok, & Wognum, 1988). Such understanding may contribute to improved analysis, interpretation, and utility of ERP topographic maps.

Surface recordings of subjects with well-known lesions show that the temporal lobe structures may not be the major generator of the scalp-recorded P3 (Stapleton, 1985). Stapleton used event-related potential stimulus protocols and the standard 10-20 EEG montage (Electrocap system) to compare two groups of human subjects. The patient group comprised 11 persons who were at least 2 years post-neurosurgery for epilepsy, which consisted of unilateral en bloc resection to remove the anterior 7 cms of the temporal lobe, including most of the hippocampus, uncus, and the dorsolateral amygdala. The patient group recordings were compared with recordings from age- and sex-matched normal subjects recruited via newspaper advertisements. From this comparison, Stapleton (1985) concluded that "patients showed no differences from unoperated control subjects in overall amplitude of P3 or any other potential measured" (pg. 140).

The Electrocap 10-20 EEG recording montage used in Stapleton's (1985) report offers acceptable clinical diagnostic power, but the comparability of the recordings to results obtained using a signal-averaged ERP recording scheme are not readily apparent; the published full 20-channel EEG tracings have been photoreduced to the size of a postage-stamp and are thus quite difficult to read.

Therefore, in the present investigation, the more commonly reported signal-averaged event-related potential recording montage is used for recording responses to simple sensory discrimination tasks. Careful attention is given to

design details and appropriateness of the analytical techniques used. Additionally, illustrative waveforms included are presented without photoreduction.

Clearly the field has much to determine about recording and analyzing event-related potentials, in addition to searching for the generator. The generator may elude us for awhile yet, because of proper ethical constraints, which make it impossible to explore possible sources in human subjects in any rigorous and systematic fashion. Of necessity other experimental approaches must be employed. Two which show promise are the use of animal models and computer modelling.

Animal Models. The archicortex of all vertebrates consists of hippocampus and amygdala, so an appropriate and convenient animal model for ERP research would seem probable. The reality is that, thus far, very few animals investigated actually produce a P3 analog, i.e., an endogenous response that meets the essential characteristics of a human P3 response: maximum positivity at 200-500 milliseconds which occurs in response to an auditory or visual oddball stimulus and whose response decreases with increasing stimulus probability and shows age-related changes of decreased amplitude and increased latency (Donchin, 1984; Courchesne, 1978; Johnson, 1986; Kaskey, 1984; Rockstroh, Elbert, Canavan, Lutzenberger, & Birbaumer, 1989; Schoenberg, 1987).

With the exception of monkeys (Arezzo, Pickoff, & Vaughan, 1981; Arthur, & Starr, 1984; Pineda, Foote, Nevill, & Holmes, 1988; Steinschneider, Arezzo, & Vaughan, 1980) and possibly cats (Harrison, et al., 1988), a P3 has only been recorded from humans. This would suggest that perhaps the basolateral amygdaloid nuclei, which are developed only in mammals and which are the best differentiated part of the primate amygdala (Sarnat, & Netsky, 1981), might be key structures for the endogenous P3 response. Furthermore, since the basolateral portion of the amygdala is continuous with the overlying hippocampus, this could potentially be the pathway by which the "state-dependent" characteristics of event-related potentials are modulated.

The cat study, (Harrison, et al., 1988), is the most invasive reported attempt at an animal model for ERP research. The researchers proposed that the septohippocampal system, which experiences cell loss with aging, might represent an important component in the P3 generator system, since the P3 typically exhibits an age-related decrease in amplitude. Screw electrodes were surgically implanted into nine adult cats. After a 2-day recovery period, baseline recordings using an auditory oddball protocol were obtained for 12 days. Eight of the animals were again anesthetized (the unlesioned animal was not electrophysiologically recorded, but was used as a control for the efficacy of the AChE histochemical staining

procedures). Bilateral lesions were placed in the medial septal nucleus and vertical limb of the diagonal band. One of the lesioned cats died. The remaining seven participated in post-lesioning recordings for another 12 days, after which they were euthanized, and samples of brain tissue were reacted for acetylcholinesterase, AChE. According to the researchers, this surgical destruction of the septal area, and the consequent depletion of hippocampal AChE, resulted in a transient appearance, followed by a decrease, and eventual disappearance of the cat P3 post-operatively. The investigators report that the most likely explanation is that the P3 is critically dependent upon cholinergic terminals in the hippocampus. Following medial septal lesions, hippocampal cholinergic terminals would exhibit transiently enhanced ACh release during the approximately 4 days necessary before complete degeneration occurred.

However, these results do not rule out the possible importance of other regions, such as the entorhinal cortex and cingulate which receive afferent input from the septal GABAergic and substance P neurons, particularly since the tissue samples from both the cingulate and entorhinal cortices also demonstrated AChE depletion by these techniques. Obliterating the septum likewise interrupts fibers which pass to the hippocampus from serotonergic and noradrenergic brainstem neurons. It would seem that the lesions were too extensive to permit satisfactory conclusion of a localizing effect in surface recordings. The recording

montage used on the cats was by necessity experimental, however the resultant waveforms were photoreduced in the publication process thus making a positive identification of the P3 component quite difficult.

The present investigation also attempted an animal model (see experiment two). While an apparent N1 analog was observed in the recordings from the dwarf lop rabbit, a P3 analog was not.

Clearly much neuroanatomical and electrophysiological work remains to be done in the search for the P3 generators, the mechanisms of event-relatedness, and the pathways of response modulation. In addition to attempts to find a suitable animal model, new computer modelling techniques are beginning to show promise.

Computer Models. A technique developed by Scherg known as brain electric source analysis, BESA, is likely to prove useful. Picton and Scherg (1991) describe the BESA technique as an "analysis-by-synthesis of the scalp recorded electrical activity. Dipole sources are postulated at particular locations within the brain and with particular orientations. [BESA] determines the time-course of activation of these dipole sources that would best explain the scalp-recorded potentials. The various spatial parameters of the dipole sources are then iteratively altered to minimize the difference between the modelled waveforms and the actual recorded data " (Picton, & Scherg,

1991, pg. 19). Using BESA, the late auditory responses are modelled to three sources within each temporal lobe which explain the scalp-recorded data with less than 1% residual variance over the response period (Picton, & Scherg, 1991).

However, as Picton and Scherg (1991) also point out, further refinement of the scalp-recording techniques is necessary, especially as it concerns noise in the tracings; the goal is to model brain signal rather than recording artifact. The BESA techniques will require larger and more rapid computing resources, as well as more advanced statistical approaches, since it would be useful to compare different solutions to such inverse problems and then to check the residual waveshapes and waveshape variances in some formal statistical manner.

## Experimental Approaches

For all that is unknown about event-related potentials, despite twenty-eight years of amassing data, we can generalize the way researchers investigate the event-related potential as psychophysiological or pathophysi-ological. Rathe Karrer, at the Institute for the Study of Developmental Disabilities at the University of Illinois at Chicago, admits that he did not think up these categories, (he credits Shagass) but he believes that the two general approaches need further emphasis.

Psychophysiological Approach. "In the psychophysiological approach, one manipulates the stimulus conditions and task requirements and studies the ERP as an index of the psychological proceses that are altered through these manipulations" (Karrer, 1984, pg. 761).

Indeed this was the approach in use when the P3 event-related potential was serendipitously discovered (Sutton, et al., 1965); the team was manipulating the auditory stimulus characteristics while recording scalp-surface electrical activity. Since then, the literature contains a greater number of increasingly complex explanations for which psychological processes are being altered, and some earlier statements have not been validated by later research. One group (Syndulko, Cohen, Tourtellotte, & Potvin, 1982) suggested that between-subject variations in P3 latency may reflect the speed and efficiency of neurocognitive processing. Others (Hillyard, & Kutas, 1983; Kutas, McCarthy, & Donchin, 1977; Renault, Ragot, Lesevre, & Remond, 1982) described the latency of P3 as an index of mental chronometry, while McCarthy and Donchin (1981) called P3 latency a metric for thought. The main difficulty with assigning any speed attribution derives from the definition of speed, which is distance over time. Without knowing the generator or the pathways there is no way of measuring distance.

Others, approaching the study of ERPs from the psychophysiological viewpoint, have attempted to relate P3

characteristics to memory capacity. Polich, Howard, & Starr (1983) reported that subjects with relatively short P3 latencies were able to retain more digits in short-term memory as measured on the Weschler Adult Intelligence Scale. Bush, Geist, & Emery (1991) found just the opposite in a sample from the high latitude population. In a review addressing the electrophysiology of cognitive processing (Hillyard, & Kutas, 1983) report that tests of memory function derived from P300 [P3] latency measures are being applied to conditions where deficiencies of recognition and storage have been implicated. Bush, Geist, & Emery (1992) observed that, in a sample of adult university students living at high latitude, the ERP characteristics were not strongly related to student performance on a series of multiple choice course examinations.

Rockstroh et al. (1989) summarized the psychophysiological descriptions of the P3 as:

"-monotonous inverse relationship between amplitude and stimulus probability

-amplitude is inversely related to subjective outcome probability

-amplitude is directly related to task relevance

-amplitude is sensitive to the interstimulus interval

-amplitude is sensitive to the informational value of the stimulus

-latency is related to time estimation but may be unrelated to response execution processes

-latency varies across the life span" (pg. 72).

The present investigation, which is only partially based on a psychophysiological approach, uses generalizable event-related potential recording methods. The description that P3 amplitude is sensitive to informational value and directly related to task relevance, is used in this project to assess construct validity (see experiment three). The description that latency varies across the life span necessitates that the subject's age be included as an independent variable.

Pathophysiological Approach. "In the pathophysiological approach an ERP component is assumed to be a robust index of a particular physiological process. When a different ERP is found a deficit is inferred in the underlying neurophysiology. One then attempts to explain the subject's behavior in terms of the biological basis" (Karrer, 1984, pg. 761-2).

Tueting (1984) summarized the research conducted from this viewpoint: "[t]he relationship of ERPs to diagnosis has revolved around the question of whether ERPs can serve as a more reliable and objective indicator of diagnosis than historical and phenomenological measures or, alternatively, whether ERPs can supplement these latter criteria, leading to 'better' diagnosis. The ability of ERPs to contribute to objective diagnosis and the more difficult question of whether ERPs can aid in determining the validity of

diagnosis--with respect to etiology of the disorder, its biological substrate and heritability, and response to treatment intervention--permeate virtually all studies of ERPs in psychopathological populations" (pg. 524).

Tueting (1984) also explains that "[m]ental disorders are believed to be associated with underlying abnormalities in neurotransmitter and neuroendocrine function. Because of this, effort has been invested in attempting to relate the phenomenology of illness to biochemical measures. Although the conceptual gap between biochemistry and behavioral phenomena often proves to be too wide, ERPs can serve as an intermediate level of analysis in this endeavor" (pg. 523-4).

At the EPIC VI (Karrer, Cohen, & Tueting, 1984) conference, a panel was convened to discuss ERPs and psychopathology, in terms of issues in the biomedical model. The panel reached concensus that the diagnosis issue was the most pressing. The other issues, of prognosis, clinical change assessment, and etiology, were all dependent upon the diagnosis issue.

Roemer & Connolly (1984) wrote the panel's opinion addressing the diagnosis issue. In their opinion "the concept of reliability of measures is critical for ERP investigators" (pg. 526). The reliability of interest to those who study biopsychiatric issues is "the consistency and accuracy of a measure, be it physiological or behavioral" (Roemer, & Connolly, 1984, pg. 526).

Reliability: Roemer and Connelly (1984) reviewed the ERP data from a number of laboratories over two decades. Based on that review, they conclude that, in general, exogenous techniques satisfy the basic requirements for a useful instrument in psychometric terms. Their review determined that "test-retest reliability is in the range of 0.80, split-half reliability is in the vicinity of 0.75, and parallel-form reliability exceeds 0.80"; however, as they are quick to point out, the "reliability of endogenous ERPs is still an open question" (Roemer, & Connelly, 1984, pg. 527-8).

The present investigation, therefore, is deliberately designed so that questions of reliability (see experiments four and five) could be forthrightly addressed. Furthermore, as previously noted, the present investigation uses common, generalizable testing protocols to facilitate comparability between laboratories elsewhere. One additional problem with using ERPs is the lack of replicable results due, in part, to the lack of equivalence between experimental protocols. Additionally, since instrumentation reliability also has implications for reliability of ERP measures, care is taken in the techniques to address those concerns.

Clinical Utility of ERPs. Despite the many problems with methodology, analysis, and theoretical bases, there is a

persistent belief among those who study ERPs that these potentials must have some useful purpose which simply has not yet been discovered. In 1990, 25-years post-ERP-discovery, a sort of "stock-taking" of this belief occurred among the ERP research community, and a series of topical summary opinions resulted. Drake (1990) evaluated the clinical utility of ERPs in neurology and psychiatry and concluded that ERPS studies are not yet of diagnostic use in psychiatric disorders since many of the disorders wax and wane in severity, making conclusions from single tests difficult. Pfefferbaum, Ford & Kraemer (1990) assessed the clinical utility of event-related potentials, giving special attention to the P3, and concluded that P3 latency was neither sensitive nor specific enough to serve as a diagnostic test. However, Pfefferbaum et al. (1990) did suggest that a useful application of the P3 component might be to help solve the differential diagnosis question of dementia vs depression or dementia (non-reversible) vs delirium (reversible). Their review also reiterates the many technical, analytical, and theoretical shortcomings of ERP recordings which have been described in some detail previously. Goodin (1990) proposed that there are many reasons for the differences of opinion regarding the clinical utility of P3, including confusion about what constitutes clinical utility. Goodin (1990) concluded that before the ultimate clinical utility is known, there will need to be systematic study to determine the reason for the

wide intercenter variability. In his opinion, Goodin (1990) also pointed out that it is important to use the simplest possible paradign to elicit the response.

Therefore, with full knowledge of the limitations of ERP techniques, and in possession of the suggestions of others similarly struggling to find the answers, the present investigation uses the simplest possible paradigm to elicit the response and undertakes to determine whether heretofore unexamined environmental variables (see experiments six, seven, and eight) might contribute to the wide intercenter variability.

## High Latitude Environmental Factors

Human Responses to Light. One human phenomenon, studied from both the psychophsiological and pathophysiological viewpoints, and which has been investigated for its relationship to the environmental variable of photoperiodicity, is a seasonal tendency in mood disorders variously called seasonal affective disorder, SAD, seasonal depression, and seasonal affective depression disorder, SADD (Gibbons, 1991). Phototherapy has been used by the psychiatric community with up to 70% of SAD patients reporting relief of symptoms. While the pineal hormone melatonin (Binkley, 1979) has been investigated for a possible role in SAD symptoms, the mechanisms of symptom onset and remission with phototherapy are not well-

understood. Despite some clinical improvement when treated with bright light, "SAD has not been proven to be a circadian rhythm disorder" (Gibbons, 1991, pg. 52).

In the course of investigating phototherapy in SAD, Duncan and Rosenthal (1986) investigated whether improvements in SAD symptoms following phototherapy were associated with changes in the P3 portion of event-related brain potentials. Duncan and Rosenthal (1986) used seven SAD patients and seven matched normal controls. Both groups were tested twice using both auditory and visual P3 protocols and 11 channels of EEG. Duncan and Rosenthal (1986) concluded that SAD patients who exhibited the most clinical improvement following phototherapy also showed the greatest increase in P300 [P3] amplitude in the visual modality. Duncan and Rosenthal (1986) concluded that a positive response to phototherapy in SAD patients was associated with a significant increase in the attentional resources that were mobilized to process visually-guided information.

Such a conclusion tends to misrepresent the actual state of knowledge with respect to ERPs. There is insufficient evidence to substantiate claims that the ERP P3 amplitude quantifies physiopsychological processes. Additionally, the test-retest reliability of ERPs over time in normal humans has not been satisfactorily established. The qualitative differences of event-related potentials recorded from SAD patients compared to asymptomatic

individuals also have not been clarified. Moreover, the extent of ERP variability from non-SAD persons, which can be reasonably attributed to natural photoperiodicity has not been established owing to the rarity of longitudinal ERP studies.

There is one longitudinal study (Anderson, et al., 1984) which suggests that some EEG characteristics might differ at high latitude. The researchers studied five normal young males, personnel from the Royal Norwegian Air Force base, living at a latitude of approximately 69 degrees north. The five participated in 2-week sleep EEG studies, four times per year (September, January, April, and June), for two consecutive calendar years. The data were nonparametrically analyzed using Friedman's two-way analysis of variance with three factors: subject, season, and workshift. The investigators concluded that EEG changes related to the time of year were detected. The change observed consisted of a trend toward increased stage I (drowsy) during the autumn and winter months. The researchers concluded that this suggested sleep lightening during the months of relative darkness.

The report is important since it is one of the few longitudinal neuroelectrophysiological studies of normal human subjects conducted at high latitude. Methodologically, however, Friedman's ANOVA may not have been appropriately used in this instance, since a basic assumption of the procedure is mutually independent blocks (Conover, 1980).

The analytical design was not clearly specified, but it appeared that the same subject, tested 4 times over 2 years, produced mutual dependency when blocked by season as the researchers apparently had done. Nonetheless, their findings suggest that part of the lack of replicability of ERP results between facilities may, in part, be related to environmental factors.

No similar high latitude investigation using event-related potentials to longitudinally study normal humans has been reported. Although at the mid-latitudes, Deldin, Duncan, and Miller (1989a; 1989b) report both a seasonal pattern in P300 variability (Deldin, et al., 1989b) and an association with light (Deldin, et al., 1989a).

Deldin, Duncan and Miller (1989a) tested 88 normal subjects (48 women) in both an auditory and visual ERP protocol. The team used a regression analysis from gender and minutes of daylight to predict P300 amplitude. Deldin et al., (1989a) concluded that P300 varied with light. These initial reports (Deldin, et al., 1989a, 1989b) of an ERP association with light has not been validated in longitudinal studies of humans living at high latitude where naturally-occurring seasonal changes in photoperiod range from 3 hours/day to 23 hours/day over the course of one year.

Consequently, in the present investigation at 64 degrees north latitude, the same normal human subjects were longitudinally studied by sampling every month for twelve

consecutive calendar months, across the full range of photoperiod.

Since ERP recording techniques require treating the background EEG as "noise" to be averaged out, stage I sleep (drowsiness) would not be captured in the tracings. Therefore, a subjective wakefulness scale was used for three purposes. First, the likert (0-10) method has a well-defined relationship to the number of hours of sleep a person experienced (Johnson, 1982), and thus the sleep-wake history can serve to monitor the relative truthfulness of the subjective sleepiness score. Second, although all subjects were self-reported free of SAD symptoms, subjective sleepiness and the sleep-wake history serve to screen for the reported SAD characteristic of hypersomnia. And third, the subjective sleepiness rating has demonstrated an experimentally useful relationship to serum melatonin levels (Wehr, 1991) which have been hypothesized to be a contributing factor to SAD symptoms, although melatonin's action on human circadian rhythms has not been fully delineated (Gibbons, 1991).

Human Responses to Geomagnetic Field Flux. Changes in human behavior related to geomagnetic field flux have also been reported (Baker, 1988; Becker, 1963; 1990; Friedman, Becker, & Bachman, 1963; 1965). Friedman et al., (1963; 1965) reported increased incidence of psychiatric ward admissions, and increased incidence of mood disorders among currently

hospitalized psychiatric patients, during periods of naturally-occurring geomagnetic storms. Using normal humans, Baker (1988) has reported an effect of small increases in the near magnetic field on a subject's ability to orient and navigate.

In the course of a recent research program dealing with the electrophysiological characteristics of mammalian pinealocytes, it was discovered that pinealocytes possess magnetic sensitivity (Semm, Schneider, & Vollrath, 1980; Welker, et al., 1983). The original program of Semm's research was to understand the physiological basis of the magnetic compass in migrating and homing animals. And while Semm concluded that the pineal is not directly involved in magnetic compass orientation, the magnetic sensitivity of pinealocytes initiated the possibility of measuring influences of the magnetic environment in the mammalian central nervous system. Semm (1992) reports that "small changes (approximately 5 degrees) of the magnetic field inclination [dip angle]...a minor change in intensity (approximately 0.01 gauss)...inhibit melatonin synthesis" (pg. 62) in rat pinealocytes.

One potential mechanism for this inhibition is described by Welker et al., 1983 who demonstrated that magnetic field stimuli inhibit nocturnal N-acetyltransferase (NAT) activity in the rat pineal. However, neither the magnetoreceptor, nor the mechanisms of such magnetosensitivity have been elucidated.

To test whether such might also occur in humans, Semm (1992) invited 14 volunteers to spend the night in a Helmholtz coil system. The controls spent the night in another, far distant room. Preliminary baseline blood samples for melatonin were collected from both groups at 2330 hours. During the night while the subjects slept, the magnetic field of the experimental group was inverted for 30 minutes [change in dip angle without change in intensity]. Blood samples for melatonin were again collected from both groups. The experimental group exhibited a 70% depression of blood melatonin concentration.

This would raise the possibility that the electromagnetic field emitted by a phototherapy lightbox, at the critical distance of one meter, might create just enough of a field change to suppress melatonin synthesis, which has been suggested as mechanism by which phototherapy provides relief of SAD symptoms. However, considerable investigation of these phenomena and their biochemical mechanisms remains to be undertaken. The human receptor mechanisms for such effects are presently unknown (Davis, 1989) and their theoretical existence is contested. Furthermore, Semm's (1992) work also suggests a need to differentiate in some manner, if possible, the effects due to light changes (phototherapy, photoperiodicity) and the effects due to natural flux in the geomagnetic field which exhibits similar circadian and infradian rhythms (Becker, 1963, 1990; Brown, 1972) (see experiments six, seven and eight).

A convenient occasion to begin to address the issue of geomagnetic field flux effects on event-related potentials manifested in Fairbanks in June, 1991. The National Oceanic and Atmospheric Administration, NOAA, released a geomagnetic storm warning (Associated Press, 1991) for an eight-day period. An area of solar flares, moving with the sun's rotation, had already triggered three such storms. Near the summer solstice, in June, Fairbanks is pointed more directly at the sun, and so this serendipitous occasion to record ERPs during the storms was opportune. Normal (nonpathological) human subjects were solicited to participate in ERP testing during the predicted 8-day period of the geomagnetic storm. The ERP recordings obtained during the storm were age- and sex-matched, retrospectively, as closely as possible to other normal human subject recordings already on file in the laboratory. The storm group had significantly different mean P3 amplitude and latency (see appendix A-1) in both the auditory and visual modalities.

The practical significance of such results, however, is not immediately apparent. This convenient investigation can be appropriately criticized, with consideration to prior discussion of ERP knowledge, since the two groups were not the same subjects. Furthermore, the magnetic field flux in the ERP recording cubicle was not being monitored at the time, and so it is possible, though unlikely, that the neurodiagnostic device may have been recording some of the

increased ambient magnetic field energy present during the storm period.

Therefore, in the present investigation, electrically quiet, shielded, nonferrous electrodes were used. Additionally, the magnetic field qualities in the recording cubicle at the time of ERP testing were included as independent variables. Data describing the ambient geomagnetic field was obtained from the College Observatory, Fairbanks, Alaska for the 12 months coinciding with ERP testing. Included as independent variables were quantitative descriptors, k-indices, of the natural geomagnetic field strength for the 3-hour period just prior to ERP testing, and the daily equivalent amplitude, Ak, for the 24-hour period prior to ERP testing. The prior 3-hour k-index was included since events which occur later in the epoch can inflate the final k-index value and some of the subjects were tested at the early portion of a 3-hour magnetogram. The prior 24-hours' Ak, is the daily equivalent amplitude conversion from the pseudologarithmic k-indices to a linear scale (Mayaud, 1980).

## PURPOSE

The primary purpose of the present investigation was to contribute to our understanding of factors which might affect human performance at high latitude by longitudinally studying the variability of event-related brain potential characteristics, both auditory and visual, in normal (non-

SAD) humans experiencing naturally occurring geomagnetic field flux and seasonal photoperiodicity.

The additive contribution of the project derives from being perhaps the longest, most systematic, longitudinal study of normal human subjects using ERP techniques. In this capacity the work adds new evidence to the questions of ERP reliability over time. Articulating answers to such questions is a necessary step toward resolving the issue of their clinical utility.

# LABORATORY METHODS

Bush, A. M., Thomas, D., Emery, S., & Geist, C. R.

# METHODS

## Design

Design. The original design consisted of two (amplitude, latency) balanced fixed effects analyses of variance, ANOVA, with repeated measures across months, of the form:

Y = mu + block + mode + hemisphere + task + wavepoint + E

where:

Y= response variable (amplitude or latency)
block= month (1=June, 2=July, 3=Aug., 4=Sept., 5=Oct., 6=Nov., 7=Dec., 8=Jan., 9=Feb., 10=Mar., 11=April, 12=May)
mode= sensory mode (1=auditory, 2=visual)
*hemisphere= head half recorded (1=left, 2=right)
*task= attention (1=attend, 2=ignore)
*wavepoint= four sites (1=N1, 2=P2, 3=P3, 4=N4)
E= random error, with 8 replicates

*The design was simplified to focus on the attended P3 response. Hemispheres were treated as subsamples rather than true replicates (see experiment two). Thus, the simplified design is:

Y = mu + block + mode + error

where Y= P3 amplitude in one, and P3 latency in the other ANOVA.

Block and mode remain as previously described.

The independent variables to be considered are:

1. Subject characteristics

-subject's age (in 1/12 months)

-subjective rating of "wakefulness"

-duration of most recent sleep epoch

-non-invasive estimate of cranial volume

2. Environment characteristics

-month of testing

-average total magnetic field in recording cubicle

-ambient geomagnetic activity at earth's surface

-photoperiod of prior 24 hours

Analytical Power. At the completion of four months of data collection, a portion of the data was examined to estimate the analytical power of the analysis, based on the noncentral F-distribution (Winer, 1971:221-230). The smallest value of practical importance was chosen to be 3

microvolts of amplitude, and 20 milliseconds of latency, for the phi calculations (S. Emery, personal communication, September 1992).

$$\text{AMPLITUDE Phi} = \sqrt{\frac{8\ (3)}{4\ (166.2934)}} \qquad \text{LATENCY Phi} = \sqrt{\frac{8\ (20)}{4\ (67.90649)}}$$

By holding the MSE constant over the 12 months projected for the study, the analytical power was estimated to be:

amplitude $F(11,84;\ 0.11)$, alpha=0.05, power > 0.89 and beta < 0.11.

latency $F(11,84;\ 0.44)$, alpha=0.05, power > 0.88 and beta < 0.12.

Thus, at the first quarter's evaluation, the probability of wrongly rejecting the null hypothesis of no differences (i.e., month1=month2=...=month12) was estimated to be < 5%, and the associated probability of wrongly accepting the null hypothesis of no differences was estimated to be less than 12%. After review of the four months assessment, no design changes were deemed necessary and the project continued as planned.

## Subjects

Sample. Subject groups are described separately (see experiments one through eight). The present investigation

does not include samples from a clinical patient population; only normal, generally healthy, human subjects participated.

Subject Conditions. Each subject was comfortably seated in the private recording cubicle, together with the recording equipment and investigator, in the behavioral sciences laboratory, located 2 floors below the earth's surface. Overhead fluorescent lights were extinguished after electrode attachment, and the room was illuminated by a single, shaded 100-watt incandescent bulb. Each testing episode lasted approximately thirty minutes during which the two four-minute ERP recordings were entirely completed within one ten-minute block. The remainder of the time was necessary for site preparation, electrode attachment, subject historical interview, and so forth. None of the subjects reported a suspected research-related injury, and none was independently noted by this investigator.

Subject Confidentiality. Confidentiality of each subject was guaranteed. All printed recordings or data records were identified by subject code only. After each recording session, ERP data were stored on diskette for later scoring and printing. Data disks were code protected and the data could not be accessed without going through the save-recall procedure, where data files were further privacy coded.

## Independent Variables

Subject Interview. At every recording session each subject was interviewed to determine: subjective wakefulness, the duration of prior sleep epoch, the presence of substances or human responses which might affect recording results (Fowler, Kelso, Landolt, & Porlier, 1988; Koppell, Roth., & Tinklenberg, 1978), and so forth.

Sleepiness. Subjects were asked to rate themselves as to how awake they felt, on a simple 1-10 likert scale, using the endpoints of 1=sound asleep and 10=wide awake. While the Stanford Sleepiness Scale is also a 1-to-10 scale, the values reflect descending order of wakefulness (1 is wide awake, 10 is sound asleep).

Since the youngest subject was nine years old, a more intuitive and straightforward rating seemed necessary. Should the subjective wakefulness rating demonstrate a significant factor weighting, it could be readily inverted to the equally subjective Stanford Scale units by the method of (10 - rating).

Sleep History. At each recording session, subjects were asked to state the time they awoke and to estimate the time they went to sleep, for the most recent prior sleep epoch. Partial hours were converted to decimal hours by dividing the partial hour minutes by sixty. For example, a

sleep epoch of 7 hours and 20 minutes, converting 20/60, would be 7.33 hours.

Cranial Volume. Each subject's head was measured with a Martin pelvimeter, marked in 0.2 cm increments from 0-50 centimeters, to determine the cranial vault dimensions. Measurements were taken according to the method of Brothwell (1981): Length = glabella to lambda, Breadth = intraparietal distance, and Height = basion to bregma.

From these measurements, the cranial capacity was estimated using the formula (Brothwell, 1981):

$$\text{Cranial Volume} = 1/3 \ ( L * B * H )$$

The calculated cranial volume was recorded to two decimal points, the same as the calibration of the calipers.

Environmental Variables. Several characteristics of the natural high latitude environment were selected as independent variables.

Photoperiod. The photoperiod recorded was the duration of ambient daylight during the most recently completed 24-hour period. The photoperiod was obtained from data provided by the National Weather Service, as published by the Fairbanks Daily News-Miner, and verified by NOAA National Weather Radio Station WXJ81, operating at 162.55 megahertz, from the National Weather Service Office in Fairbanks, Alaska. As with the sleep history, the partial hour minutes were

converted to decimal hours by dividing the number of minutes by sixty.

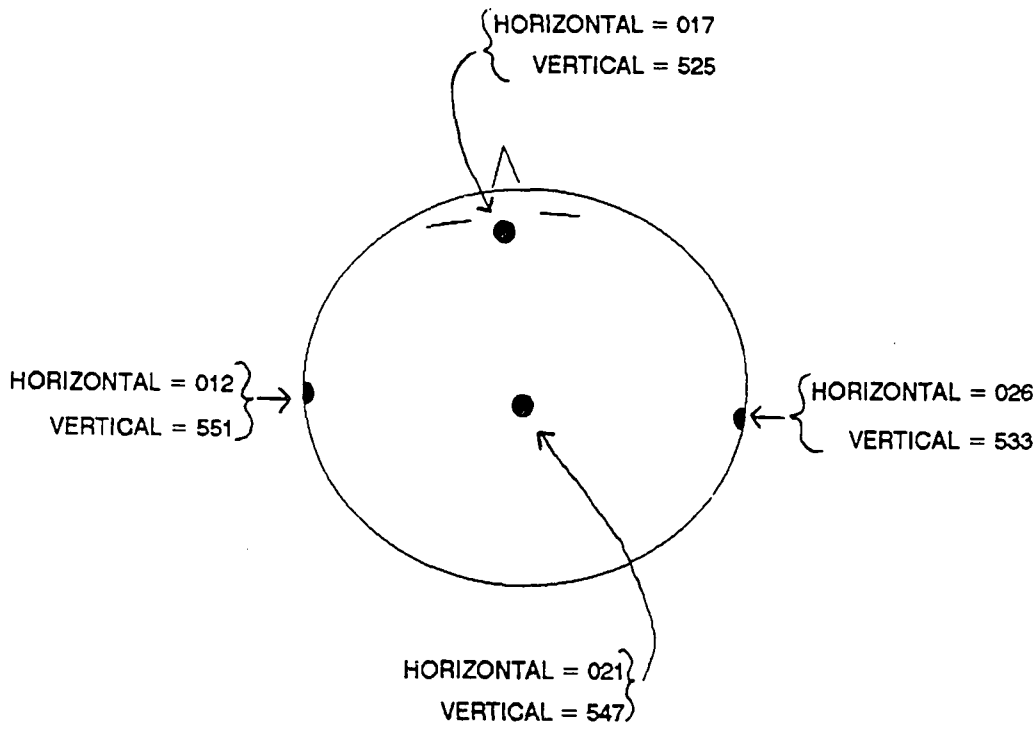
Magnetic Fields: Recording Cubicle. The ambient magnetic field in the recording cubicle at the time of testing was measured with a Walker Scientific FGM-3D1 fluxgate magnetometer. The FGM-3D1 has been designed for applications which include measuring Earth's field vector components and residual field measurements, and for calibrating solenoids and Helmholtz coil systems. The FGM-3D1 magnetometer possesses full scale ranges of 20 milligauss, 200 milligauss, and 2000 milligauss, with 0.01 milligauss resolution and 0.5% accuracy traceable to NIST, National Institute of Standards and Technology, the former National Bureau of Standards.

Using the magnetometer probe, both the vertical vector and the horizontal vector were measured at each of the four electrode attachment sites: left ear, right ear, cranial vertex, and forehead as shown in Figure 1. Horizontal vector direction was nose-forward, and vertical vector direction was earth-down; all subjects sat in the same orientation in the room. Vectors were measured using the 2000 milligauss scale, since ambient geomagnetic field strength is typically on the order of 500 milligauss (Mayaud, 1980). The total magnetic field, TMF, was calculated (Walker Scientific Inc., magnetometer operator's manual) for each electrode attachment site independently.

FIGURE 1. Calculation of the total magnetic field, TMF, around the subject's head at the time of event-related potential recordings.

I. TOTAL MAGNETIC FIELD = $\sqrt{(\text{HORIZONTAL})^2 + (\text{VERTICAL})^2}$

II. INCLINATION (DIP ANGLE) = ARCTAN $\left(\frac{(\text{VERTICAL})}{(\text{HORIZONTAL})}\right)$




| SITE | VECTORS | TMF | DIP ANGLE |
|---|---|---|---|
| Left Mastoid | H = 012<br>V = 551 | 551.13 milligauss | 88.75 degrees |
| Right Mastoid | H = 026<br>V = 533 | 533.63 milligauss | 87.21 degrees |
| Vertex | H = 021<br>V = 547 | 547.40 milligauss | 87.80 degrees |
| Forehead | H = 017<br>V = 525 | 525.27 milligauss | 88.14 degrees |
| | AVERAGE | = 539.35 | = 87.95 |

The four fields were then averaged by the four electrode sites to give the average TMF for each subject's head at the time of recording, as shown in Figure 1.

Ambient Surface Fields. Data describing the ambient geomagnetic field were provided by the staff at the College Observatory, located on the UAF campus. The data consist of the twelve monthly National Oceanic and Atmospheric Administration, NOAA, Form #76-133, which coincide with the 12 consecutive months of ERP testing. An example of the data provided by the Observatory is shown in Table 1. Each NOAA Form lists the k-indices recorded in 3-hour epochs based on Greenwich Civil Time. Each 24-hour period has eight 3-hour k-indices which are totalled into the Sum for that 24-hour period.

Two characteristics of the k-index render it inappropriate for calculations. First, the index measures deviation from background, thus it has no true zero point. Second, the k-index scale specifies a class of ranges which have varying unit length. Therefore the k-index is treated as an ordinal categorical variable (Mayaud, 1980).

The measure appropriately used for calculations is the Ak, daily equivalent amplitude, for the 24-hours, which is also provided on the NOAA form #76-133. The Ak is a conversion of the pseudologarithmic k-scale to a linear scale (R. Hunsucker, personal communication, February, 1993).

Table 1. Sample of geomagnetic field data sheet.

NOAA FORM 76-133 (9-72) U. S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

**MAGNETIC ACTIVITY**

**(Greenwich civil time, counted from midnight to midnight)**

OBSERVATORY: College, Alaska

MONTH AND YEAR: May, 1991

| DATE | K-INDICES 00-03 | 03-06 | 06-09 | 09-12 | 12-15 | 15-18 | 18-21 | 21-24 | SUM | Ak |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 3 | 4 | 5 | 6 | 5 | 3 | 3 | 33 | 34 |
| 2 | 5 | 4 | 6 | 6 | 6 | 6 | 5 | 5 | 43 | 61 |
| 3 | 3 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | 32 | 32 |
| 4 | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 21 | 12 |
| 5 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 16 | 8 |
| 6 | 2 | 2 | 2 | 0 | 2 | 2 | 1 | 1 | 12 | 5 |
| 7 | 1 | 3 | 2 | 3 | 1 | 1 | 2 | 1 | 14 | 7 |
| 8 | 2 | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 23 | 15 |
| 9 | 2 | 1 | 2 | 2 | 1 | 3 | 4 | 2 | 17 | 10 |
| 10 | 1 | 2 | 3 | 4 | 4 | 2 | 2 | 2 | 20 | 13 |
| 11 | 1 | 1 | 1 | 2 | 0 | 1 | 0 | 0 | 6 | 2 |
| 12 | 0 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 9 | 4 |
| 13 | 2 | 3 | 3 | 6 | 5 | 5 | 6 | 2 | 32 | 38 |
| 14 | 2 | 4 | 4 | 6 | 6 | 7 | 4 | 2 | 35 | 49 |
| 15 | 2 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 16 | 9 |
| 16 | 2 | 1 | 1 | 1 | 2 | 2 | 5 | 3 | 17 | 12 |
| 17 | 5 | 6 | 7 | 5 | 4 | 3 | 2 | 2 | 34 | 47 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 | 3 |
| 19 | 1 | 1 | 0 | 0 | 0 | 1 | 2 | 2 | 7 | 3 |
| 20 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 9 | 4 |
| 21 | 1 | 0 | 0 | 3 | 2 | 3 | 3 | 2 | 14 | 8 |
| 22 | 2 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 26 | 19 |
| 23 | 4 | 3 | 3 | 3 | 6 | 6 | 3 | 3 | 31 | 33 |
| 24 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 3 | 34 | 33 |
| 25 | 5 | 6 | 6 | 6 | 5 | 5 | 4 | 3 | 40 | 53 |
| 26 | 3 | 4 | 4 | 5 | 5 | 6 | 3 | 3 | 33 | 34 |
| 27 | 5 | 3 | 4 | 6 | 6 | 5 | 3 | 3 | 35 | 41 |
| 28 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 37 | 40 |
| 29 | 5 | 3 | 6 | 5 | 5 | 4 | 3 | 3 | 34 | 37 |
| 30 | 3 | 3 | 3 | 6 | 5 | 5 | 2 | 2 | 29 | 29 |
| 31 | 4 | 4 | 5 | 7 | 6 | 6 | 4 | 3 | 39 | 56 |

TIME SCALE ON MAGNETOGRAMS: 20 mm/hr

SUDDEN COMMENCEMENTS

| d | h | m |
|---|---|---|
| 13 | 08 | 57 |
| 16 | 20 | 41 |
| 31 | 09 | 01 |

POSSIBLE SOLAR-FLARE EFFECTS BASED ON INSPECTION OF GRAMS ALONE (WITHOUT REFERENCE TO DATA FROM OTHER SOURCES)

| BEGIN d | BEGIN h | BEGIN m | END d | END h | END m |
|---|---|---|---|---|---|

The 3-hour epoch corresponding to the time of each subject's testing period was identified by adding 9 hours to local time to convert to Greenwich Civil Time. However, since some subjects were recorded at the start of a 3-hour epoch, and since events which happen near the end of 3-hour magnetogram can affect the k-index for that period, the prior 3-hour epoch's k-index was also used. Summarizing measures of the prior 24-hours' geomagnetic field, the sum and Ak, were included as independent variables (see Table 1, and also experiments six, seven, and eight).

Dependent Variables

In the design specified, and using only the attended P3 portion of the ERPs recorded, the dependent variables are:

| | |
|---|---|
| Auditory amplitude, left | (n=8, repeated x 12) |
| Auditory amplitude, right | (n=8, repeated x 12) |
| Auditory latency, left | (n=8, repeated x 12) |
| Auditory latency, right | (n=8, repeated x 12) |
| Visual amplitude, left | (n=8, repeated x 12) |
| Visual amplitude, right | (n=8, repeated x 12) |
| Visual latency, left | (n=8, repeated x 12) |
| Visual latency, right | (n=8, repeated x 12) |

Testing order. The left and right sides of each subject's head were recorded separately, but simultaneously, in each sensory modality. The auditory protocol preceeded the visual protocol by fewer than 3 minutes in every instance, and electrodes remained where initially placed for both

tests. Using the nonparametric one-sample runs test of randomness (Zar, 1984) on the subject identification codes, it was concluded that the testing order of the subjects was random over the course of 12 calendar months.

Electrode Placement. Four sites for electrode placement were used for noninvasive scalp surface recordings of the event-related potentials: bilateral mastoids (Au-1 and Au-2, unlinked), cranial vertex (Cz, common reference), and the central forehead (ground). Each site was gently abraded until pink using Omniprep compound and a cotton-tipped applicator, to reduce skin impedance. A 9 millimeter gold-cup electrode was filled with Grass electrode paste and secured to each preppped site with a cotton ball and hypoallergenic adhesive tape. Impedances were verified to be less than 5k ohms (Cadwell Quantum-84 operator's manual recommendations, pg. 11.8) prior to beginning ERP testing.

## Neurodiagnostic Recording Equipment

In order to ensure comparability of the results to those from other laboratories, stimulus and recording parameters were matched to those reported in the ERP literature. Event-related potentials were recorded using a Cadwell Laboratories Quantum-84, 4-channel, neurodiagnostic system which is a software controlled portable system. In Roemer and Connolly's (1984) discussion of the reliability of ERPs, they comment that "reliability of instrumentation is another

possible contributor to difficulties in replication. The literature is remarkably silent regarding calibration standards for [ERP] research" (pg. 526). Therefore, detailed information about the instrumentation used for this project is included here.

The Cadwell Quantum-84 is a distributed processing system. Each of the major subsystems of the unit contains its own microprocessor and associated memory, commercial ports, and specialized circuits that perform functional logic and signal decoding. The subsystems communicate with one another over dedicated data links. Thus, each subsystem accomplishes its tasks independently of the others, which enhances both the speed of operations and efficiency. The system was inspected, installed, and calibrated on site at the UAF campus Behavioral Sciences Laboratory, by Thomas Cadwell of Cadwell Laboratories, during August, 1990, prior to the start of the work. The data for the present investigation was recorded entirely during the 3-year post-inspection warranty period. Additionally, this investigator received supervised training by Thomas Cadwell in the Quantum-84 system's operation prior to beginning the high latitude investigations.

Preamplification. The electrodes attached to the subject's head are initially connected to a 4-channel preamplifier which contains all gain stages and high-pass filter components. Since a preamplifier might have some amplitude

drift over time, the calibration procedure (Cadwell operator's manual, pg. 11.10) is routinely performed monthly. The offset voltage [chopper-stabilization to reduce thermal drift (Hoenig, 1980, pg. 194)] for each channel was observed to be within specified tolerances at every calibration, and the preamplifier required no adjustments within its warranty period. ERPs were recorded with the preamplifier switch set in the "normal" mode (as opposed to NCVS); thus the subjects were completely isolated from the Quantum-84 so that stray currents could not flow through to ground. The analog high-pass filter in the preamplifier was set at 1.00 hertz, to restrict the input to those frequencies that could be evaluated by the digitization rate and sweeptime of the analog-to-digital, A/D, converter (Picton, et al., 1984).

Analog-to-Digital Conversion. Digital low-pass filtering and A/D conversion are accomplished internally on the A/D board of the Quantum-84 device. Each of the four channels has 8-bit resolution at 18 kHz. The low-pass digital filter was set at 100 hertz (Manufacturer's recommendation when using a 4-channel preamplifier, pg. 4.15).

Averaging. The electrical activity recorded from the scalp after a sensory stimulus contains the response to the stimulus (the "signal") and other unrelated potentials (the "noise"). The process of averaging is one of the most

powerful techniques available to increase the signal-to-noise ratio of the recording (Picton, et al., 1984). The Quantum-84 averager board has its own local processor and memory. The averager board directs the A/D board as a peripheral, and uses a separate state sequencery for high-speed averaging. Each stimulus condition (attend, ignore) recording from each side of the head (left, right) was independently averaged. At the onset of each stimulus presentation, one second of EEG was coincidentally captured, filtered, and averaged, separately but simultaneously, for each of the four designated channels (ch-1 = left, ignore; ch-2 = left, attend; ch-3 = right, ignore; ch-4 = right, attend).

Stimulus Generation. The stimulus sequence generator was operated in the pseudorandom mode: no two consecutive target stimuli. Additionally, a new random starting point (seed value) was selected for each subject's tests using a table of random digits (Netter, Wasserman, & Kutner, 1985). In this manner, the auditory or visual stimuli were randomly presented at a rate of one per second by using a 0.30 second pulse with a 0.70 second delay.

Auditory Oddball Detection Paradigm. Auditory stimuli were presented to each subject, binaurally, through calibrated and balanced audiometric headphones (Amplivox Audiocups). The subject's task was to sit quietly for four minutes while

listening through the headphones, and to silently count the number of times the target tone was heard. A target was defined as a stimulus to be attended to by counting.

ignored tone: p = 0.85, 1000 hertz
80 dB binaural presentation

attended tone: p = 0.15, 2000 hertz
80 dB binaural presentation

Each tone was cosine-ramped over 0.30 seconds as follows:

rise time = 0.10 seconds
plateau time = 0.10 seconds
decay time = 0.10 seconds

The subject's count of the targets heard was compared against the computer count of the targets presented to ascertain that the subject was adequately performing the task requested. No subject deviated more than +/- 2 targets.

Visual Oddball Detection Paradigm. Visual stimuli were presented to each subject, binocularly, via a black-and-white 12-inch-square Sanyo VM4515 video monitor screen. Each subject was seated perpendicular to the screen at a distance of 22 inches. The subject's task was to sit quietly for four minutes, with eyes focused on a central screen fixation marker, and to count the number of times the target stimulus was seen. Visual target definition is analogous to auditory target definition. Stimuli consisted of a series of black-and-white pattern-reversing squares.

Visual angles were determined using the trigonometric functions of right triangles (Smith, 1986) and the method described by Hubel (1988) as shown in Figure 2.

As with the auditory stimuli, the subject's count of the visual targets observed was compared against the computer's count of the visual targets presented to ascertain that the subject performed the task requested. No subject's count deviated more than +/- 2 of the actual number of targets presented.

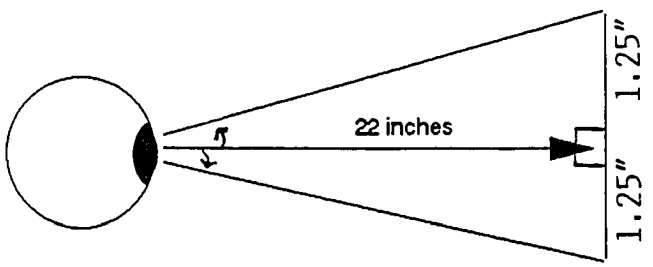
Scoring the Waveforms. There are two basic approaches to identifying components in the waveforms. The first is based upon the actual waveform and consists of identifying its peaks and valleys. The second determines which parts of the waveform are similarly affected by experimental manipulations (Picton, et al., 1984).

The current investigation uses the first approach, based on the actual waveform, and identifies the peaks and troughs through visual inspection. On-screen cursors were used to apply the first derivative test for relative extrema (Kohlman, & Denlinger, 1988). Such approaches have been judged well suited for evaluating normal waveforms (Picton, et al., 1984). The P3 waveform was thus identified, in the attended stimuli tracings from each side of the head, in each sensory modality, as shown in Figure 3.

Amplitude of the P3, in microvolts, was measured as the distance between two on-screen horizontal cursors. Time-

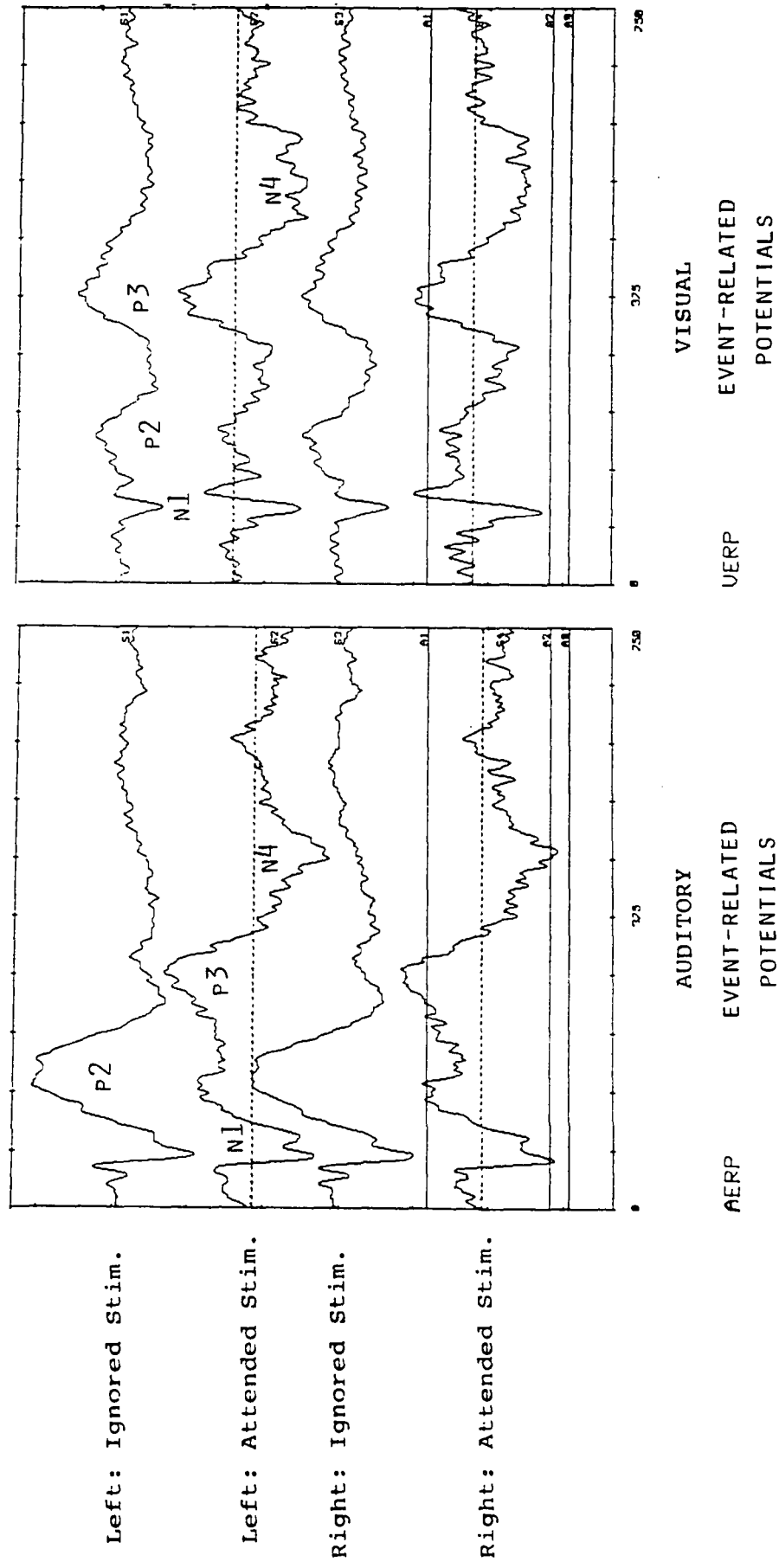
Figure 2. Method of calculating visual angles.

$$\text{VISUAL ANGLE} = 2 * \text{ARCTAN}\left(\frac{\text{OPPOSITE}}{\text{ADJACENT}}\right)$$




| STIMULUS | SIZE | ARC SUBTENDED |
|---|---|---|
| VIDEO MONITOR..... | 12-INCH SQUARE ..... (6"CENTER) | 30.51 DEGREES |
| IGNORE PATTERN..... | 2-1/2" SQUARES..... (1.25" CENTER) | 6.50 DEGREES |
| ATTEND PATTERN..... | 1-INCH SQUARES..... (0.5" CENTER) | 2.60 DEGREES |

Figure 3. Example of event-related potentials recorded by methods described.



zero of stimulus onset served as the defined baseline and the relative extrema of P3 served as the measuring endpoint. The Quantum-84 measures the amplitude between the two cursors to two decimal places, and statistical analyses of the amplitude are reported to one significant digit beyond what the Quantum-84 actually measures.

Latency of the P3, in milliseconds, was measured as the distance between two on-screen vertical cursors. Time-zero of stimulus onset served as the starting point, and the relative extrema of P3 served as the measuring endpoint. The Quantum-84 measures the latency between the two markers to two decimal places, and statistical analyses of the latency are reported to one significant digit beyond what the Quantum-84 actually measures.

## Data Analyses and Graphical Representations

The illustrative ERP waveforms are presented without photoreduction and were produced by the Quantum-84 system's built-in Alps printer using an oil-based inking dot-matrix. When necessary, the lines have been augmented, with great care and the aid of a magnifying lens, using simple black ink to ensure readability after reproduction. Those which have required darkening of the ink have been identified as "inking augmented".

QuatroPro Version 4.0 (Borland, 1991) was used to prepare summary data tables, and the bivariate graphs.

SYSTAT (Wilkinson, 1990) was used to evaluate the reliabilities of the ERP data. SAS/STAT (1989) was used for assessing normality of data distribution, performing the general linear model analysis of variance for repeated measures, and for Tukey's HSD pairwise comparisons. BMDP (Dixon, 1990) was used for descriptive statistics and principal components analysis.

The present investigation was conducted in eight stages. The results of each are described separately in experiments one through eight which follow.

# EXPERIMENT ONE

## A Comparison of Two Methods for Measuring P3 Amplitude in Human Event-Related Brain Potentials

Bush, A. M., Geist, C. R., & Emery, S.

## EXPERIMENT ONE

### A Comparison of Two Methods for Measuring P3 Amplitude in Human Event-Related Brain Potentials

As described in the ERP literature, there are two common methods for measuring the amplitude of P3. One way is to measure the absolute voltage difference, in microvolts, between the P3 peak and subsequent negative trough. This is the peak-to-trough method. The other way is to measure the absolute voltage difference, in microvolts, between the P3 peak and a defined baseline point prior to P3. This is the relative to baseline method. Both methods are routinely employed, although the method relative to a baseline is becoming incorporated into the newer technology, especially those with automated peak-finding routines. The difference in amplitude measuring techniques may contribute to the interfacility variability in results reported for similar studies in the ERP literature.

The purpose of this investigation was to evaluate the two methods of measuring P3 amplitude in order to ascertain which method was more likely to lead to the correct conclusion that responses recorded from two groups

(specifically chosen for their similarities) are not significantly different.

Ho: Peak-to-Trough results are the same as the Relative-to-Baseline results.

Ha: Results from the two methods differ.

Sample. Two groups with a total of 56 subjects (41 females and 15 males, ages 14 - 81 years).

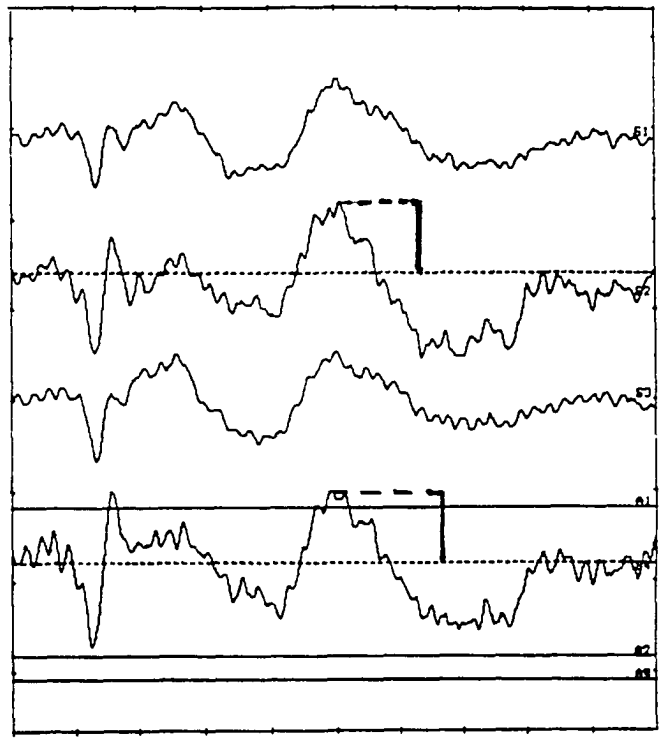
Group-1 consisted of 32 uncompensated healthy human volunteers, all residents of the immediate geographical region. In group-1 were 21 females (ages 20 - 81 years, M = 37.85 yrs, STD = 16.94) and 12 males (ages 14 - 76 years, M = 32.93 yrs, STD = 16.02).

Group-2 consisted of 23 uncompensated healthy human volunteers, all residents of the immediate geographical region. In group-2 were 20 females (ages 28 - 70 years, M = 33.47 yrs, STD = 11.31), and 3 males (ages 19 - 77 years, M = 32.5 yrs, STD = 28.37).

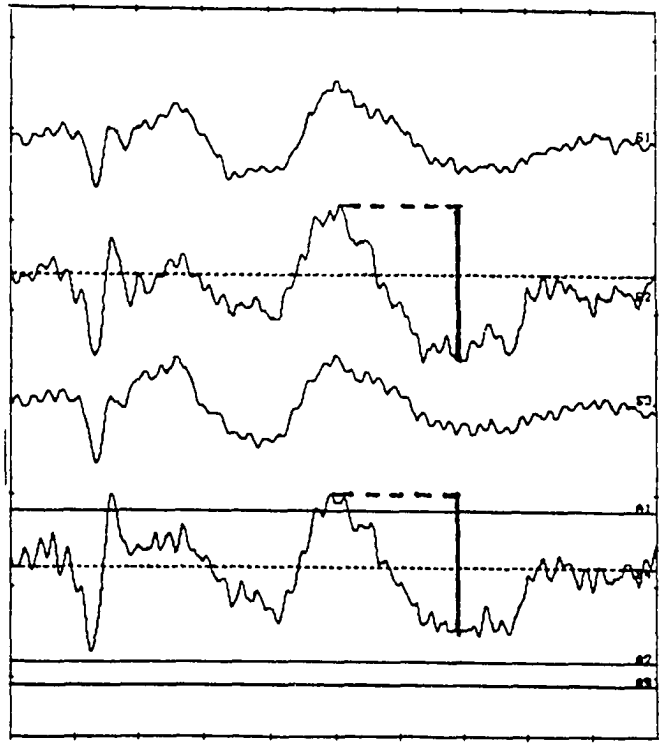
Methods. Subjects were recorded in the auditory oddball paradigm only, and the ERP responses recorded were measured by both methods, peak-to-trough and relative-to-baseline. The two measuring methods are illustrated in Figure 4.

Figure 4. Comparison of Two Methods of Measuring P3 Amplitude.

Relative-to-Baseline
P3 amplitude is measured as the absolute voltage difference between the P3 peak and the time-zero baseline.



Peak-to-Trough
P3 amplitude is measured as the absolute voltage difference between the P3 peak and the subsequent negative trough.



Results. Descriptive statistics for the two groups are presented in table 2. The two data from the two groups are graphically compared in figure 5. By measuring P3 amplitude peak-to-trough, it is concluded that the two groups are significantly different ( $t = 6.8997$, $df = 54$, $p < 0.005$). However, by measuring P3 amplitude relative-to-baseline, it is concluded that the two groups are similar ($t = 0.549$, $df = 54$, $0.30 < p < 0.40$).

Conclusions. By measuring the P3 amplitude in the peak-to-trough method, the conclusion is reached that the ERP responses from two groups of normal healthy human subjects are significantly different. Furthermore, as can be seen in Table 2 and Figure 5, this measuring method resulted in wider data ranges, and larger standard deviations.

By measuring the P3 amplitude relative to a prestimulus baseline, the conclusion is reached that the ERP responses from the two groups of normal healthy human subjects are not significantly different. As can be seen in Table 2 and Figure 5, measuring P3 amplitude relative-to-baseline resulted in narrower data ranges, and smaller standard deviations which would be expected from two groups of similar subjects.

Since event-related potentials are highly variable responses, careful attention must be given the technical details of recording and measuring, to minimize technical

Table 2. Comparison of P3 amplitude data obtained by two measuring methods.

uv = microvolts

| METHOD | | GROUP 1 (n=32) | GROUP 2 (n=23) |
|---|---|---|---|
| Peak-to-Trough | max. | 23.00 uv | 36.00 uv |
| | min. | 5.20 uv | 5.20 uv |
| | mean | 10.75 uv | 12.20 uv |
| | STD. | 4.52 uv | 7.37 uv |
| Relative-to-Baseline | max. | 12.00 uv | 23.00 uv |
| | min. | 2.00 uv | 2.00 uv |
| | mean | 6.60 uv | 6.49 uv |
| | STD. | 1.63 uv | 5.14 uv |

Testing for equality of the mean P3 amplitude recorded from two similar groups.

$$t^* = t\ (1 - \text{alpha} / 2;\ n1 + n2 - 2)$$

where: alpha = 0.05

$$t = \frac{\overline{Y} - \overline{Z}}{s(Y-Z)}$$

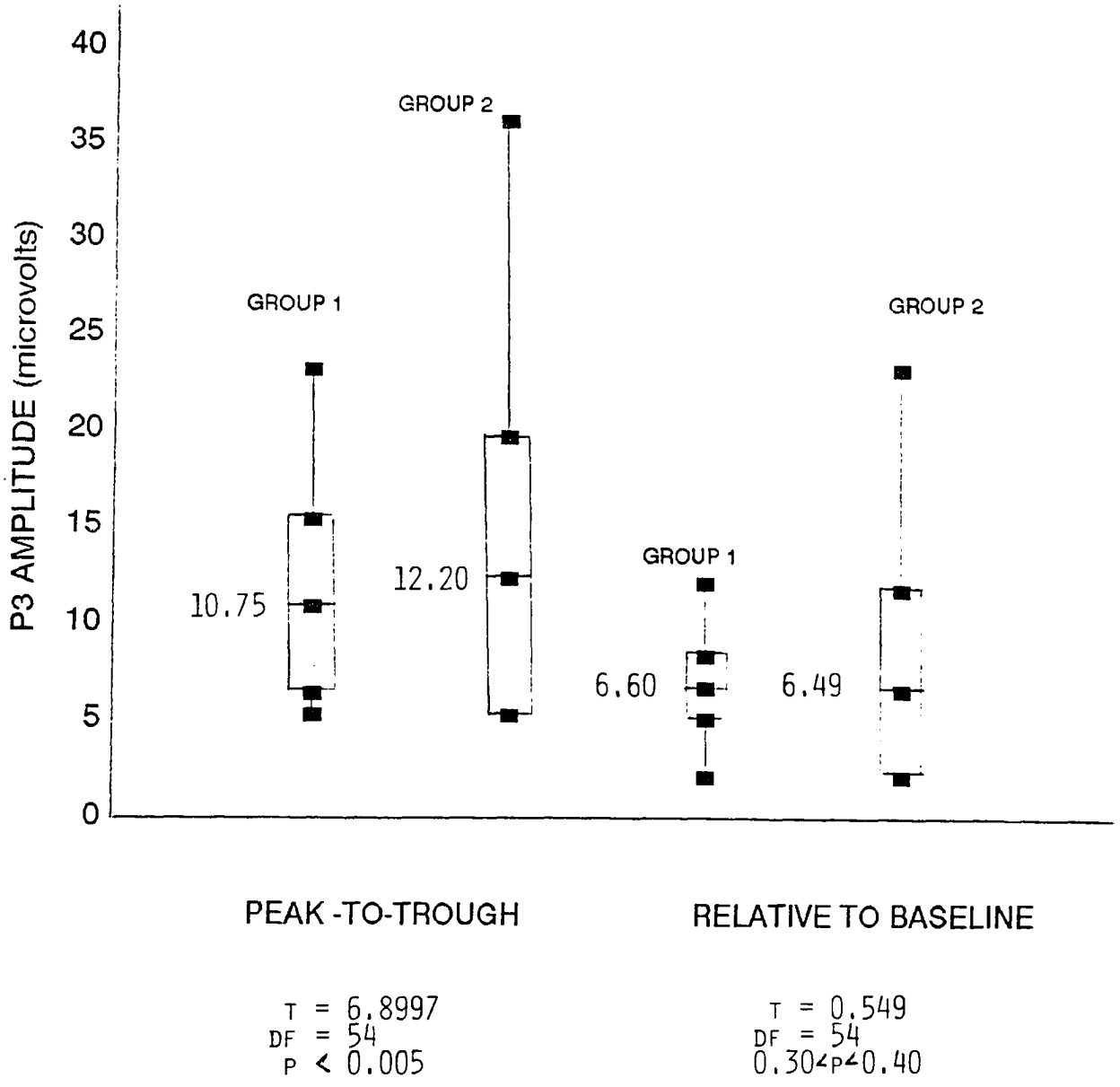
I. Peak-to-trough

$t = 6.8997,\ p < 0.005$

II. Relative-to-Baseline

$t = 0.549,\ 0.30 < p < 0.40$

Figure 5. Comparison of two methods of measuring P3 amplitude in two similar groups of human subjects.



artifact, and to properly arrive at meaningful conclusions well-supported by the data obtained. Of the two methods that were evaluated, measuring P3 amplitude relative-to-baseline best achieves that research goal, and is the method used in subsequent portions of this report.

# EXPERIMENT TWO

## An Attempt at an Animal Model for Event-Related Brain Potential Recordings.

Bush, A. M. & Geist, C. R.

## EXPERIMENT TWO

A technique for noninvasively recording auditory event-related brain potentials from awake, unsedated, unrestrained rabbits.

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Journal of Neuroscience Methods
John S. Kelly, Editor-in-Chief
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Purpose: To identify a P3 analog in a convenient animal model would permit greater control of experimental variables while investigating event-related brain potentials.

Ho. A human P3 analog is not evident in the rabbit ERPs.
Ha: A human P3 analog can be identified.

Methods. Four dwarf lop rabbits (Figure 6), housed in an enriched environment (Figures 7, 8, and 9), and well-accustomed to each step of the noninvasive recording protocol (Figure 10) served as the subjects. The rabbits

Figure 6. Four female dwarf lop rabbits comprised the sample. The four were littermates and had been raised in an enriched environment, including extensive human handling, since birth.

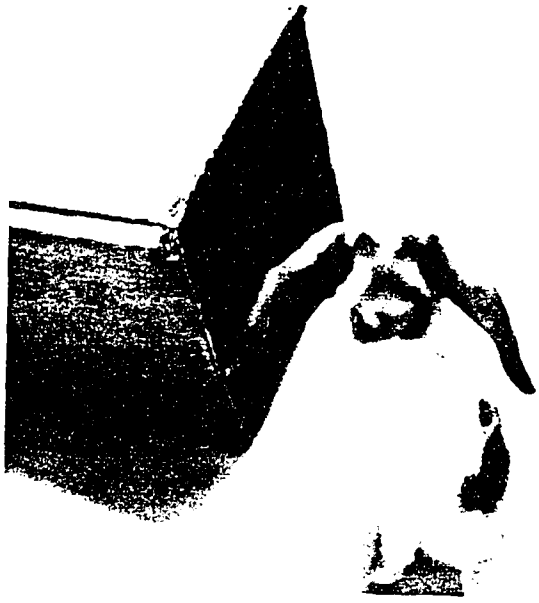


Figure 7. Rabbits were singly housed in cages, but were treated to an enriched communal environment for several hours each week.

Figure 8. Animals were recorded noninvasively. One can notice the bald spots on the rabbits' heads. A commercial hair removal lotion was used to denude portions of ears and scalp.

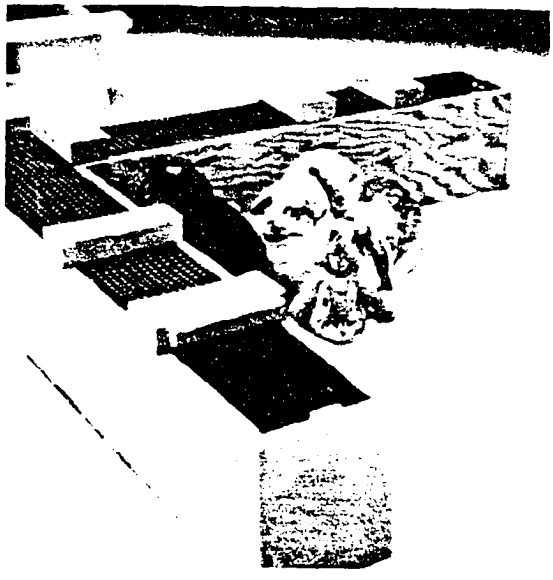


Figure 9. Electrodes were attached to denuded areas, noninvasively, using the same materials as for human subjects. The headphone holder and recording board were custom-built (C. Bush) for this purpose.

Figure 10. Each animal was thoroughly conditioned to all steps in the ERP recording procedure. Animals would sit quietly where placed on the board for the four minute recording period. A food reward followed each recording session and the animal was then released into the enriched communal play area.

Figure 11. Sample of electrical activity recorded from a rabbit during an auditory ERP oddball detection paradigm.

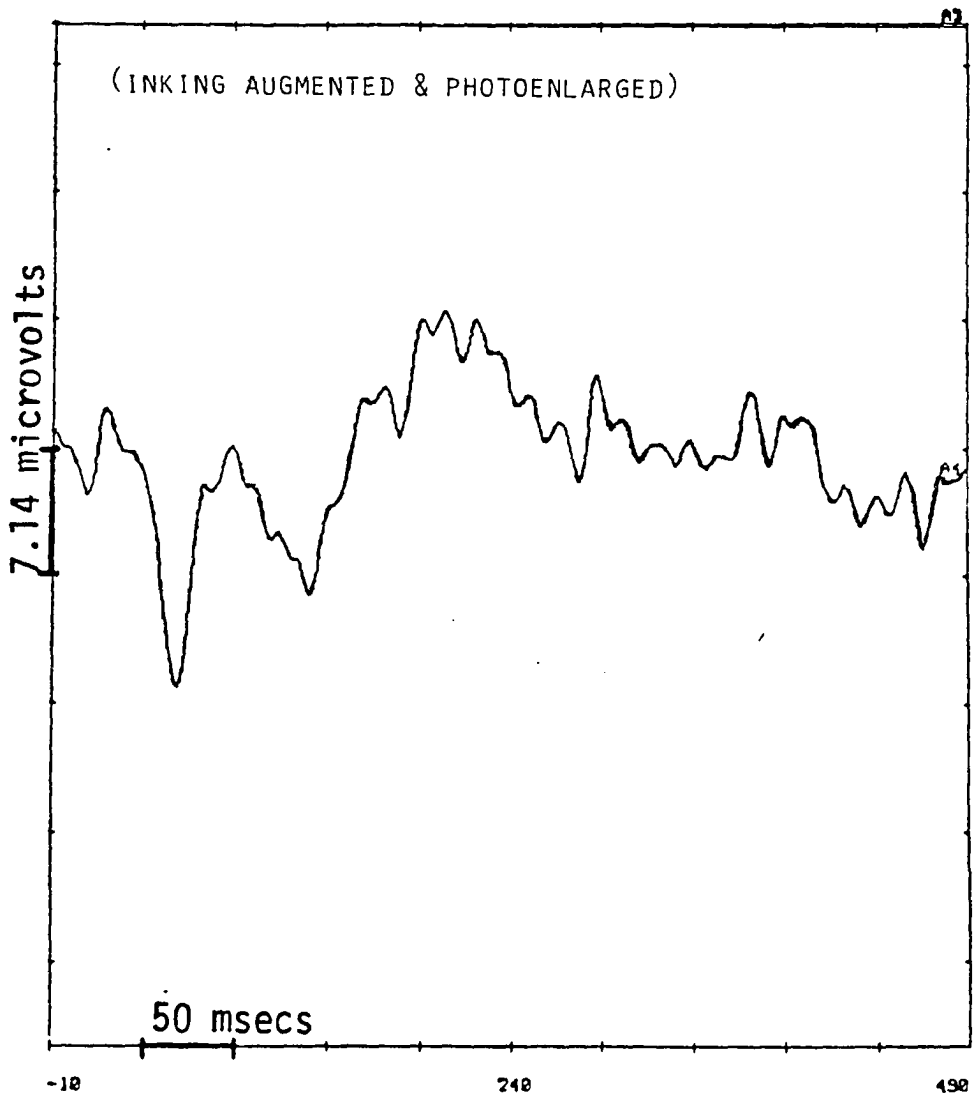
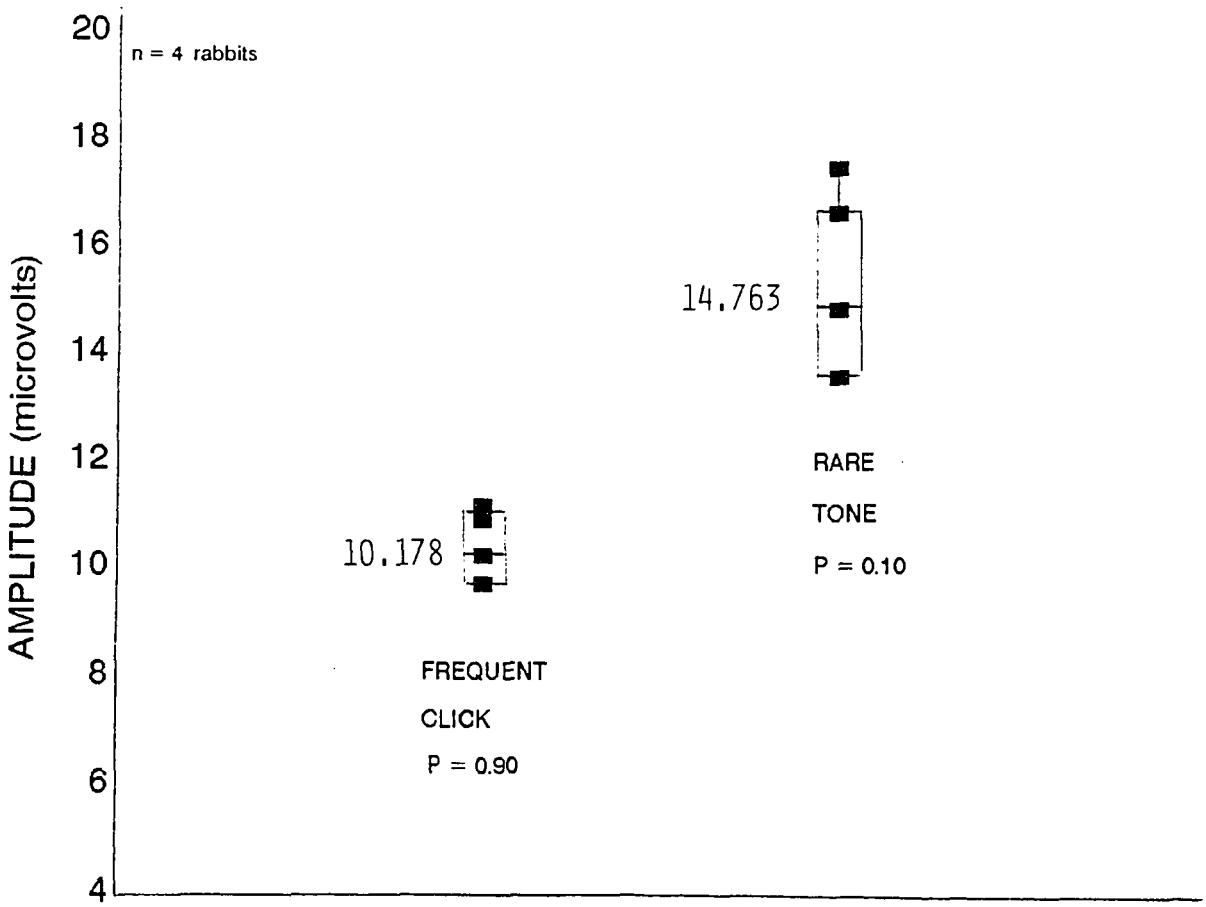


Table 3. Description of auditory ERP data recorded from the rabbits. Data is for the initial large negativity illustrated in figure 11.

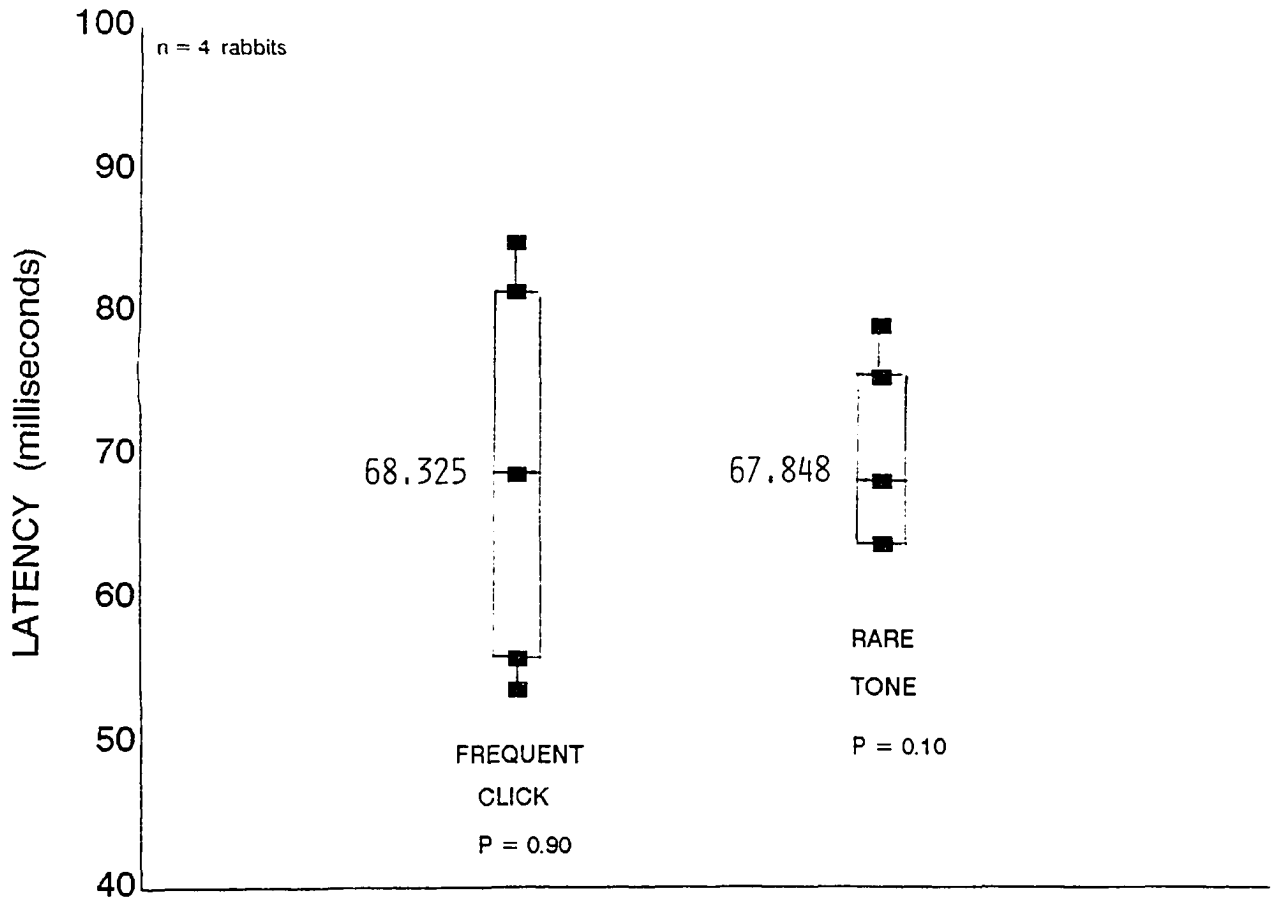
| | AMPLITUDE (microvolts) | | LATENCY (milliseconds) | |
|---|---|---|---|---|
| | Click | Tone | Click | Tone |
| n= | 4 | 4 | 4 | 4 |
| minimum | 9.650 | 13.530 | 53.380 | 63.540 |
| maximum | 11.110 | 17.440 | 84.540 | 78.610 |
| range | 1.460 | 3.910 | 31.160 | 15.070 |
| mean | 10.170 | 14.763 | 68.325 | 67.848 |
| variance | 0.453 | 3.244 | 162.362 | 52.406 |
| std. dev. | 0.673 | 1.801 | 12.742 | 7.239 |
| std. error | 0.337 | 0.901 | 6.371 | 3.620 |
| skewness | 0.717 | 1.091 | 0.172 | 1.096 |
| kurtosis | -1.102 | -0.709 | -0.993 | -0.717 |

Figure 12. Comparison of the average amplitude of the large negativity recorded from the four rabbits using a human auditory ERP stimulus protocol.




t = 4.142
df = 3
p = 0.026

Figure 13. Comparison of the average latency of the large negativity recorded from the four rabbits using a human auditory ERP stimulus protocol.




t = 0.131
df = 3
p = 0.904

were recorded with a two-stimuli auditory protocol, frequent click and rare tone, as for human ERPs. Although no identifiable P3 was noted, a large negativity was consistently observed in the rabbit recordings where a human N1 would normally be expected (Figure 11).

Results. The amplitude and latency of the large negativity during the two auditory conditions are summarized in table 3. The amplitude of the negativity during the two stimulus conditions is graphically compared in Figure 12. The mean amplitude of the negativity in response to the rare tone (M = 14.763 microvolts) was significantly larger ($t = 4.142$, $df = 3$, $p = 0.026$) than the mean amplitude of the negativity in response to a frequent click.

The latency of the negativity during the two stimulus conditions is graphically compared in Figure 13. The mean latency of the negativity in response to a rare tone (67.848 milliseconds) was not significantly different ($t=0.131$, $df = 3$, $p = 0.904$) than the latency of the negativity in response to a frequent click.

CONCLUSIONS:

A human P3 analog was not identified in the rabbit recordings, however, an early large negativity was identified at about the same latency as the N1 in humans. In humans, the N1 is presumed to correspond to the stimulus set according to the Broadbent/Treisman model of a filter theory for attention (Rockstroh, et al., 1989). The mean latency of the potential did not change significantly with a change in the physical stimulus parameters, however, the mean amplitude of the negative potential in the rabbits did vary significantly when the physical stimulus parameters changed. Thus, this negative potential recorded in the rabbit represents a relatively late stage of cortical processing, and may be analogous to a human N1 event-related potential.

Although the rabbit is a convenient animal to work with for ERP recordings, the portion of interest to human performance investigations, the P3, was not evidenced in the rabbit recordings.

# EXPERIMENT THREE

## An Examination of the Construct Validity of the Event-Related Potential P3 Response

Part One: P3 amplitude is sensitive to the informational value of a stimulus and directly related to task relevance.

Part Two: P3 amplitude has an inverse relationship to stimulus probability.

Bush, A. M., & Emery, S.

## EXPERIMENT THREE: PART ONE

### An Examination of the Construct Validity of the P3 Portion of the Auditory and Visual Event-Related Potentials.

The accumulating data reported in the ERP literature is converging on a description of the P3 amplitude as sensitive to the informational value of a stimulus and directly related to task relevance. This description of P3 is selected as the trait to be evaluated for construct validity of event-related potential recordings.

A valid test is one which measures what it is intended to measure. Of the various psychometric measures of test validity, content validity is heavily dependent upon subjective judgement, while criterion validity is often too restrictive for working with content areas for which there is disagreement about adequate outside criterion (Groth-Marnat, 1990). Construct validity, on the other hand, assesses the extent to which the test measures a theoretical trait.

If the P3 portion of the ERPs is sensitive to the informational value of a stimulus, it is expected that the ERP characteristic of P3 amplitude would differ between the frequent stimulus and the rare stimulus. If P3 amplitude is directly related to task relevance, it is expected that P3 amplitude would be higher in response to those stimuli to be

attended and counted when compared to those stimuli to be ignored.

The significance of P3 latency changes in healthy normal humans is a matter of some disagreement in the ERP literature. An evaluation of the construct validity of P3 latency is included here as a contribution to that discussion.

Ho-1: P3-amplitude attended = P3-amplitude ignored

Ha-1: P3-amplitude attended > P3-amplitude ignored

Experiment-wise alpha = 0.05 (0.05 / 2 tests = 0.025).

Ho-2: P3-latency attended = P3-latency ignored

Ha-2: P3-latency attended differs.

Experiment-wise alpha = 0.05 (0.05 / 2 tests = 0.025).

Subjects. Subjects are the longitudinal study group.

Methods. Subjects participated in both auditory and visual ERP testing using the oddball detection paradigm previously described, with P3 amplitude measured relative-to-baseline.

Results. The data for the amplitude and latency, in both the auditory and visual protocols, are summarized and compared in table 4.

The amplitude of P3, during the two stimulus conditions (attend, ignore) and for both sensory modalities are

Table 4. An evaluation of the extent to which P3 amplitude and P3 latency measure the theoretical trait.

| | AMPLITUDE (microvolts) | | LATENCY (milliseconds) | |
|---|---|---|---|---|
| | Auditory | Visual | Auditory | Visual |
| overall mean | 5.629 | 9.267 | 329.116 | 383.231 |
| overall STD. | 6.139 | 6.910 | 38.287 | 43.845 |
| pooled STD. (within groups) | 4.017 | 4.007 | 38.054 | 41.934 |
| t-statistic | 25.752 | 27.651 | 2.398 | 6.088 |
| | $p < 0.001$ | $p < 0.001$ | $p < 0.017$ | $p < 0.001$ |

graphically compared in Figure 14. The mean auditory P3 amplitude (10.27 microvolts) for an attended stimulus is significantly larger ($p < 0.001$) than the mean amplitude for an ignored stimulus (0.989 microvolts). The difference of the auditory means for the two stimulus conditions is 9.281 micro-volts. The mean visual P3 amplitude (14.89 microvolts) for an attended stimulus is significantly ( $p < 0.001$) larger than the mean visual P3 amplitude for an ignored stimuls (3.64 microvolts). The difference of the visual means for the two stimulus conditions is 10.724 microvolts.

The latency of P3, during the two stimulus conditions (attend, ignore) and for both sensory modalities are graphically compared in Figure 15. The mean auditory P3 latency to an attended stimulus (324.48 milliseconds) is significantly shorter ( $p < 0.017$) than the mean auditory P3 latency to an ignored stimulus (333.75 milliseconds). The difference of the two auditory means is 9.27 milliseconds. The mean visual P3 latency to an attended stimulus (396.19 milliseconds) is significantly ( $p < 0.001$) longer than the mean visual P3 latency to an ignored stimulus (370.27 milliseconds). The difference of the two visual means is 25.92 milliseconds.

Conclusions. As can be seen, the amplitude of the P3 consequent to an attended auditory or visual stimulus is significantly greater than the amplitude of the P3 following

Figure 14. Comparison of the P3 ERP amplitude from attended rare stimuli and ignored frequent stimuli.

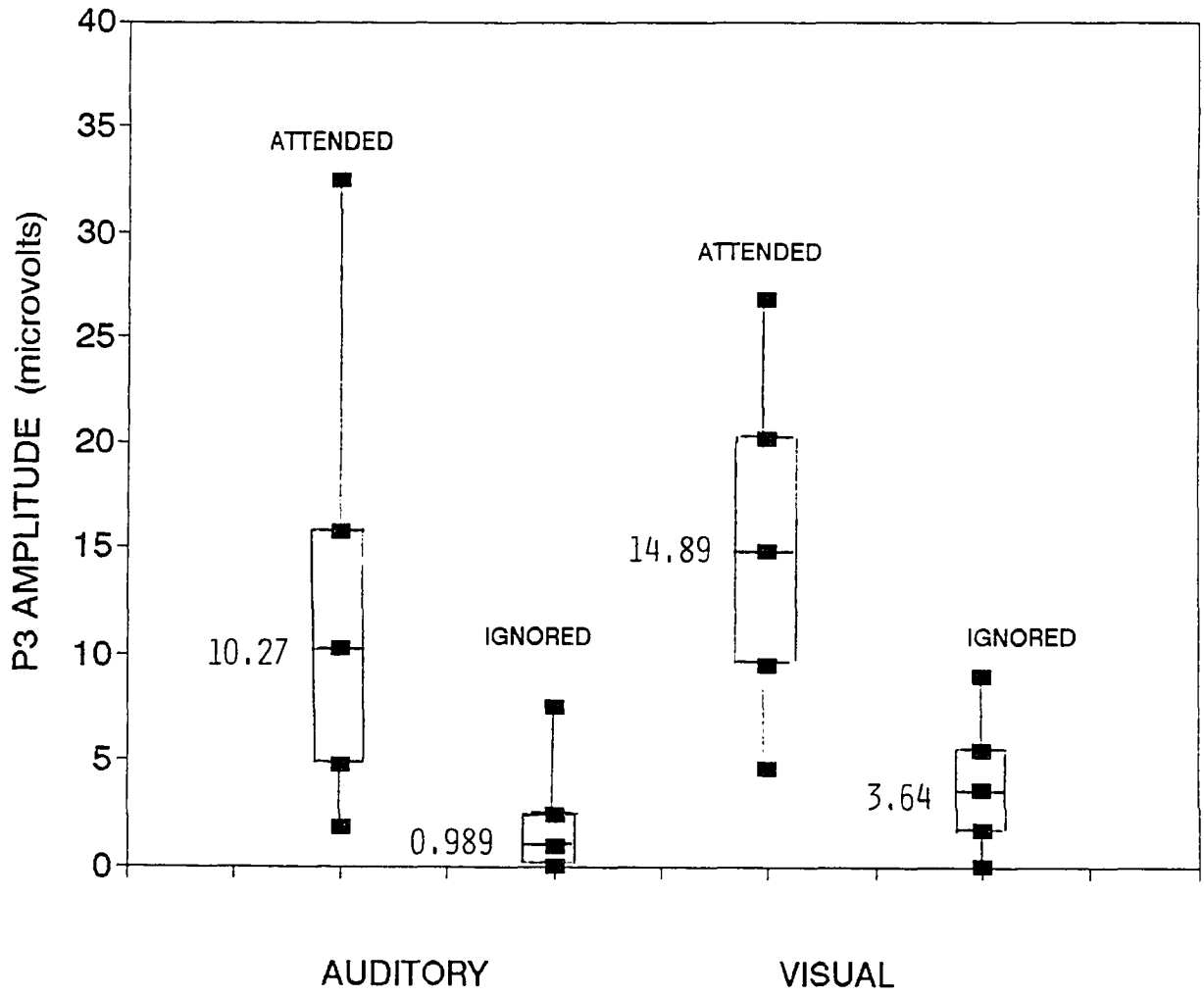
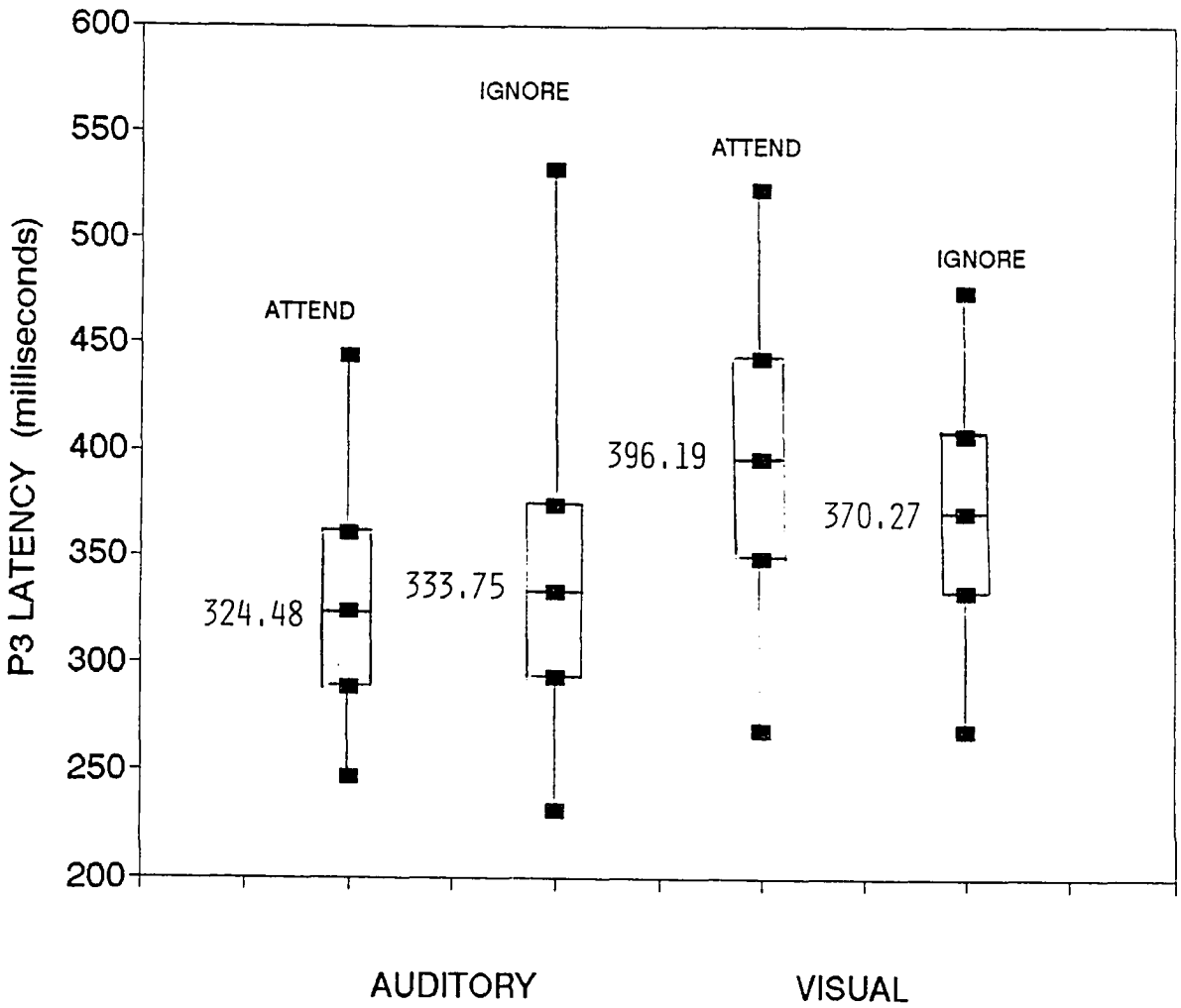


Figure 15. Comparison of the P3 ERP latency from attended rare stimuli and ignored frequent stimuli.



an ignored stimulus. The theoretical traits of the P3 portion of the event-related responses (sensitive to informational value and directly related to task relevance) were accepted for the longitudinal study group of human subjects.

As can also be seen, the latency of the P3 consequent to an attended auditory or visual stimulus differs from the latency of the P3 following an ignored stimulus. The mean latency of the auditory P3 response was shorter for the tone to be counted than for the tone to be ignored, whereas the mean latency of the visual P3 response was longer for the image to be counted than for the image to be ignored. Since the attended and ignored responses were recorded from the identical subjects, without intervening changes in electrode placement, this finding is interpreted as not indicative of a lifespan variation and not indicative of technical artifact. As previously discussed, P3 latency has been related in the literature to categorization time and has been explored in terms of a relationship to short-term memory. Recall, for example, that the number of digits retained in short-term memory has been reported to be associated both with shorter P3 latencies (Polich, Howard, & Starr, 1983) and with longer P3 latencies (Bush, Geist, & Emery, 1991). For either sensory modality, the relationship of P3 latency to response execution processes remains unclear.

## EXPERIMENT THREE: PART TWO

### An Evaluation of P3 Response to Increasing Target Probability

In a recent summary (Rockstroh, 1990) of experimental evidence concerning ERP responses, another P3 trait becoming evident is an inverse relationship with target stimulus probability. An earlier review (Johnson, 1988) proposed a model for factors influencing P3 amplitude. Among the experimental variables known to affect P3 amplitude is what Johnson (1988) termed subjective probability. It is due to this trait of the P3 event-related potential that most researchers customarily use relatively rare target stimuli ($0.10 < p\text{-target} < 0.20$) to achieve a maximally robust response.

The purpose of this investigation was to validate that theoretical trait of P3 in a sample from the subarctic population. It was expected that P3 amplitude will decrease as the probability of a target stimulus was increased. Although such a relationship has not been reported in the literature for the P3 latency, the latency response to increased target probability was also included for completeness.

Ho-1: P3 amplitude does not differ among the three target probabilities: 0.15, 0.30, 0.45.

Ha-1: P3 amplitude is largest for relatively low target probability (0.15).

Ho-2: P3 latency does not differ among the three target probabilities: 0.15, 0.30, 0.45.

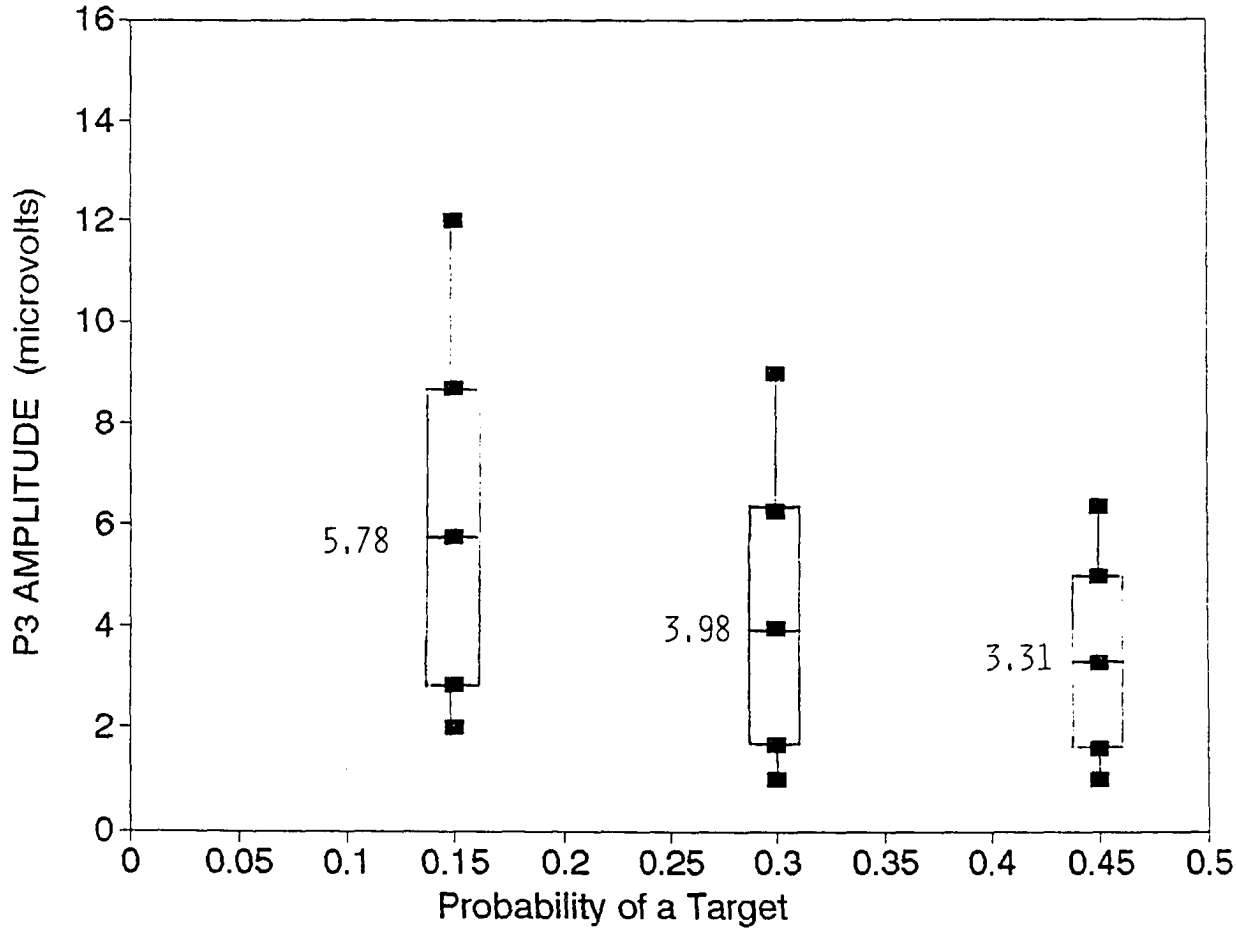
Ha-2: P3 latency response of at least one target probability differs from the others.

Subjects. Thirty-four uncompensated normal adult humans who voluntarily participated in recordings to evaluate the two measuring methods, also participated in sequential auditory ERP recordings with increasing target probability. Of the thirty-four subjects, 19 were females (ages 28 - 40 years, M = 32.93 yrs, STD = 3.68) and 15 were males (ages 23-52 years, M = 37.7 yrs, STD = 4.43).

Methods. The subjects participated in auditory event-related potential testing using methods previously described. The three trials were recorded consecutively, without electrode manipulation, and with increasing target probability on each trial: 0.15, 0.30, 0.45.

Results. Changes in the auditory P3 amplitude which occur as the target probability is increased are graphically presented in Figure 16. The auditory P3 amplitude was significantly different ($F = 9.975$, $df = 2,99$; $p < 0.001$) for the three rare target probabilities compared. The matrix of pairwise comparisons, using Tukey's HSD, for

Figure 16. Changes in the auditory P3 amplitude as the probability of a target stimulus is increased. Data are from the same subjects recorded in consecutive trials.




Bartlett Test for Homogeneity of Group Variances
Chi-Square = 8.927, df = 2, p = 0.012.

ANALYSIS OF VARIANCE

| SOURCE | SUM SQUARES | DF | MEAN SQUARE | F | PROBABILITY |
|---|---|---|---|---|---|
| Between Groups | 110.433 | 2 | 55.216 | 9.975 | < 0.001 |
| Within Groups | 548.008 | 99 | 5.535 | | |

auditory P3 amplitude is shown in Table 5. As can be seen, the P3 amplitude response to the rarest target probability, p = 0.15, differed significantly from p-target = 0.30 (p = 0.006) and from p-target = 0.45 (p < 0.001). The mean auditory P3 amplitude was largest (5.78 microvolts) when the target probability was smallest, p-target = 0.15.

Changes in auditory P3 latency which occurred as the target probability was increased are graphically presented in Figure 17. The mean auditory P3 latency differed significantly (F = 3.357, df = 2,99; p = 0.039) between the three target probability conditions. The matrix of pairwise comparisons, using Tukey's HSD, of the mean P3 latency is shown in Table 5. As can be seen, the auditory P3 latency is not significantly different for p-target = 0.15 and p-target = 0.30, however, p-target = 0.15 and p-target = 0.45 do differ significantly (p = 0.029).

Table 5. Matrices of pairwise comparisons of the mean changes in P3 response characteristics consequent to increasing target probability.

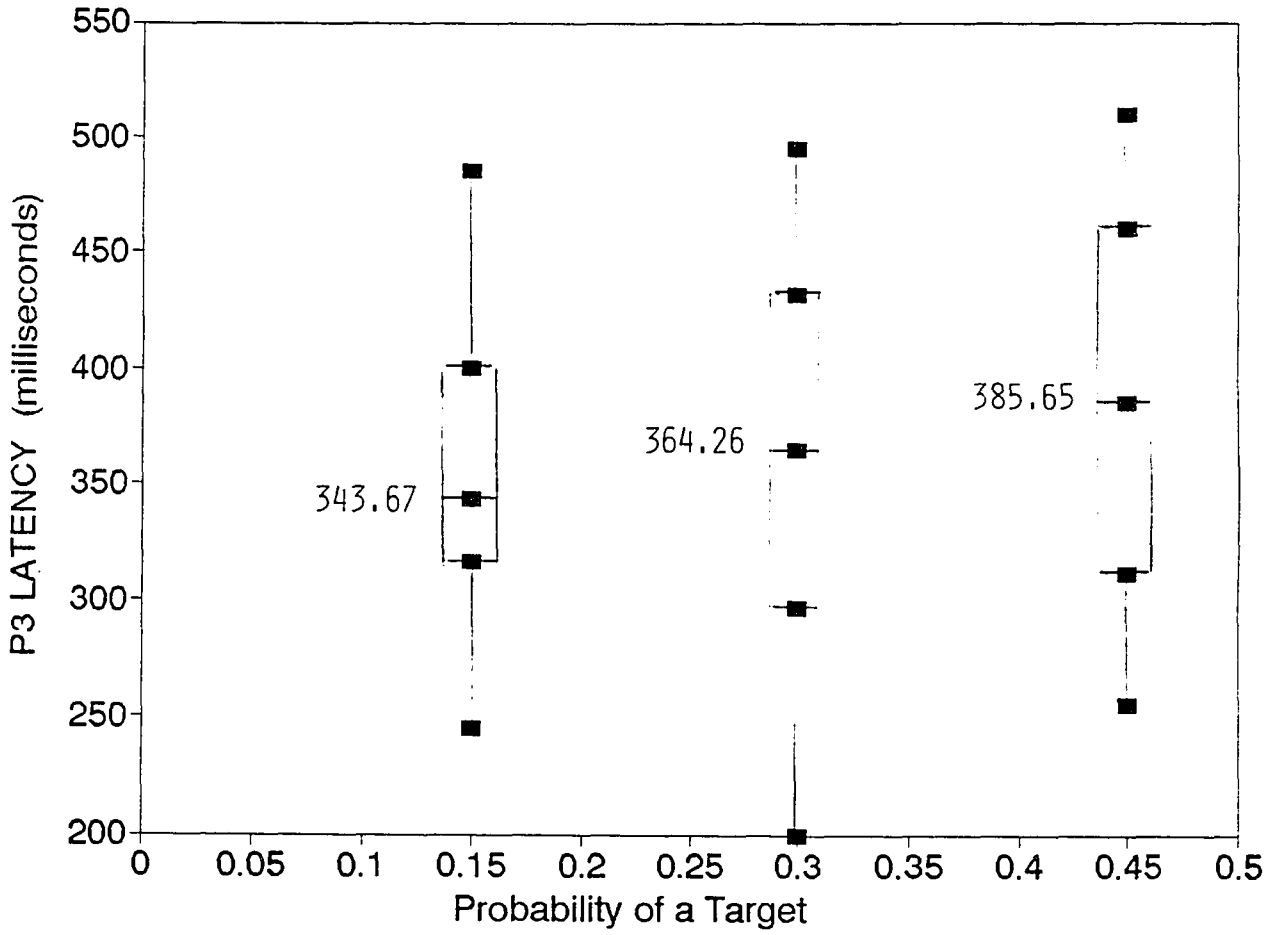
MATRIX OF PAIRWISE ABSOLUTE MEAN DIFFERENCES (Tukey's HSD) IN AUDITORY P3 AMPLITUDE AS A RESPONSE TO INCREASING TARGET PROBABILITY.

| Probability of a Target: | 0.15 | 0.30 | 0.45 |
|---|---|---|---|
| 0.15 | 0.000<br>p = 1.00 | | |
| 0.30 | 1.799<br>p = 0.006 | 0.000<br>p = 1.000 | |
| 0.45 | 2.463<br>p = 0.000 | 0.665<br>p = 0.477 | 0.000<br>p = 1.00 |

MATRIX OF PAIRWISE ABSOLUTE MEAN DIFFERENCES (Tukey's HSD) IN AUDITORY P3 LATENCY AS A RESPONSE TO INCREASING TARGET PROBABILITY.

| Probability of a Target: | 0.15 | 0.30 | 0.45 |
|---|---|---|---|
| 0.15 | 0.000<br>p = 1.00 | | |
| 0.30 | 20.588<br>p = 0.415 | 0.000<br>p = 1.00 | |
| 0.45 | 41.971<br>p = 0.029 | 21.382<br>p = 0.388 | 0.000<br>p = 1.00 |

Figure 17. Changes in the auditory P3 latency as the probability of a target stimulus is increased. Data are from the same subjects recorded in consecutive trials.




Bartlett Test for Homogeneity of Group Variances
Chi-Square = 2.281, df = 2, p = 0.320.

ANALYSIS OF VARIANCE

| SOURCE | SUM SQUARES | DF | MEAN SQUARE | F | PROBABILITY |
|---|---|---|---|---|---|
| Between Groups | 29949.588 | 2 | 14974.794 | 3.357 | 0.039 |
| Within Groups | 441561.824 | 99 | 4460.220 | | |

Conclusions. The mean auditory P3 amplitude declined as the target probability was increased. It was concluded that the theoretical trait of an inverse relationship between P3 amplitude and target probability is valid for the sample from a subarctic population. It was also concluded that, of the three probabilities investigated, P3 amplitude response was maximally robust at relatively low target probabilities.

The mean auditory P3 latency tended to become longer as the target probability was increased. An ANOVA suggested that the three target probabilities had significantly different P3 latency responses. The subsequent Tukey's HSD pairwise comparisons identifed the P3 latency response to a 15% target probability as signifantly different from the response to a 45% target probability. It was also observed that the standard deviation of P3 latency responses was smallest for the 15% target probability.

Therefore, in further investigations of variables which affect event-related responses, a target probability of 0.15 was selected.

# EXPERIMENT FOUR

## An Evaluation of the Reliability of ERP Measurement

Part One: Split-Half Reliability (left vs right)
Bush, A. M., & Geist, C. R.

Part Two: Test-Retest Reliability (time-1 vs time-2)
Bush, A. M., Zamora, J. P., & Geist, C. R.

Part Three: Parallel Forms (auditory vs visual)
Bush, A. M., & Geist, C. R.

Part Four: Parallel Forms (linked mastoids vs unlinked)
Bush, A. M., Alexander, J., & Geist, C. R.

## EXPERIMENT FOUR-INTRODUCTION

The reliability of a response measurement refers to its degree of stability, consistency, predictability, and accuracy. The purpose of testing reliability is to estimate the degree to which the test (here, ERP) varies due to error (Groth-Marnat, 1990). The reliability was evaluated in four separate parts:

1. split-half: left side of head vs right side
2. test-retest: time-1 vs time-2
3. parallel forms: auditory vs visual
4. parallel forms: linked mastoids vs unlinked

Ideally, clinicians hope for correlations of at least 0.90 in tests that will be used to make decisions about individuals, wheras a correlation of 0.70 is generally adquate for research purposes (Groth-Marnat, 1990). A review (Roemer, & Connolly, 1984) of the reliability of exogenous responses demonstrates correlations of: split-half (0.75), test-retest (0.80), and parallel forms (0.80).

The reliabilities of the endogenous event-related responses must be evaluated against these reported benchmarks, as ERP reliabilities are still a matter of investigation.

## EXPERIMENT FOUR: PART ONE

### An Evaluation of the Split-Half Reliability of Event-Related Potentials in Two Sensory Modalities.

The split-half technique is useful for evaluating the reliability of a trait in which there is a high degree of fluctuation. The test is given only once, split in half, then the two halves are correlated. The split-half method thus provides a measure of the internal consistency of the data obtained (Groth-Marnat, 1990).

In the ERP recording methods previously described, responses are recorded from both sides of a subject's head independently, but simultaneously, thus forming natural split-halves. The purpose of this investigation was to evaluate the degree of internal consistency of the data obtained.

Ho: Split-half reliability > or = 0.75.
Ha: Split-half reliability < 0.75.
(Pearson's Product Moment Correlation)

Subjects. Thirty-two uncompensated human volunteers, normal adults, participated. Of the 32 subjects, 16 were female (ages 19-30 years, M = 21.187 yrs., STD = 3.08 yrs.), and 16 were male (ages 19-45 years, M = 25.56 yrs., STD = 6.76 yrs.).

Methods. All 32 subjects were recorded in both auditory and visual ERP protocols according to the methods previously described. Only the P3 response to an attended stimulus was considered.

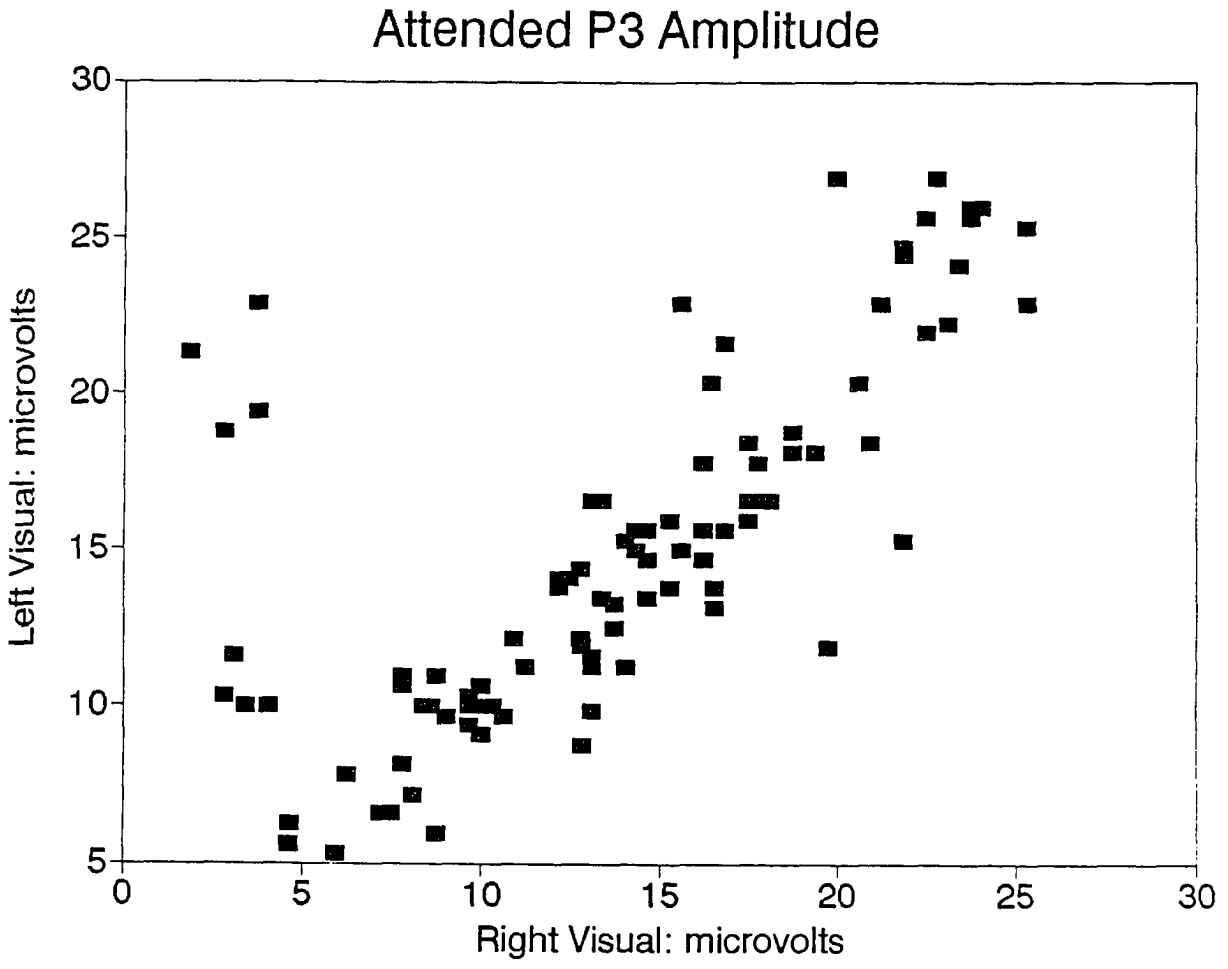
Results. The visual attended P3 amplitudes for left and right halves are graphically compared in Figure 18. The Pearson Product Moment Correlation for left visual vs right visul P3 amplitude was r = 0.910.

The auditory attended P3 amplitudes for left and right halves are graphically compared in Figure 19. The Pearson Product Moment Correlation for left auditory vs right auditory P3 amplitude was r = 0.971.

The visual attended P3 latencies for left and right halves are graphically compared in Figure 20. The Pearson Product Moment Correlation for left visual vs right visual P3 latency was r = 0.962.

The auditory attended P3 latencies for left and right halves are graphically compared in Figure 21. The Pearson Product Moment Correlation for left auditory vs right auditory P3 latency was r = 0.989.

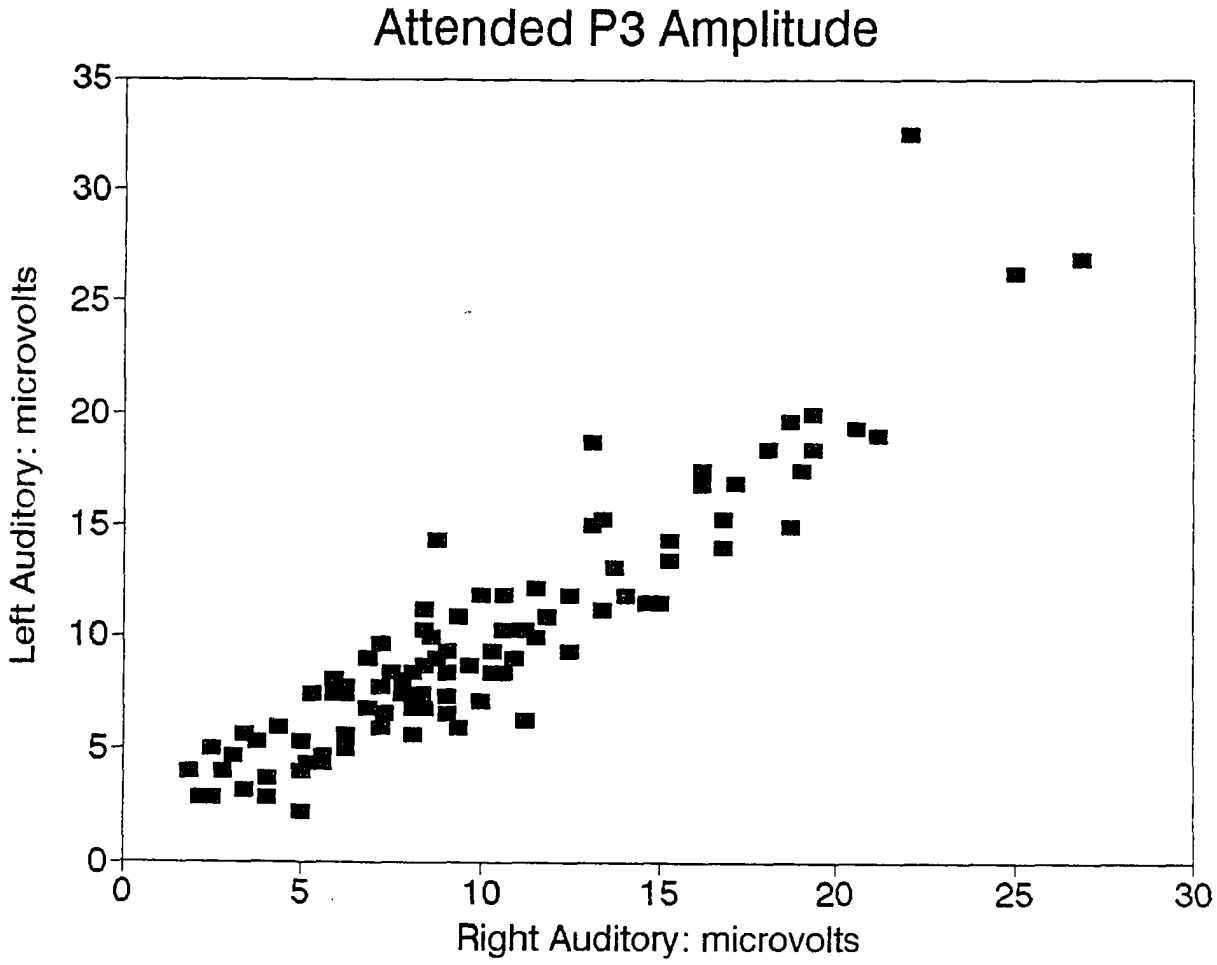
Figure 18. An evaluation of the split-half reliability of visual P3 responses recorded from two sides of the subject's head simultaneously.




| | VISUAL AMPLITUDE | |
|---|---|---|
| | Left | Right |
| n | 32 | 32 |
| minimum | 1.87 | 2.03 |
| maximum | 27.84 | 23.75 |
| mean | 8.84 | 9.08 |
| std. dev. | 5.82 | 5.52 |

PEARSON'S PRODUCT MOMENT CORRELATION: r = 0.910

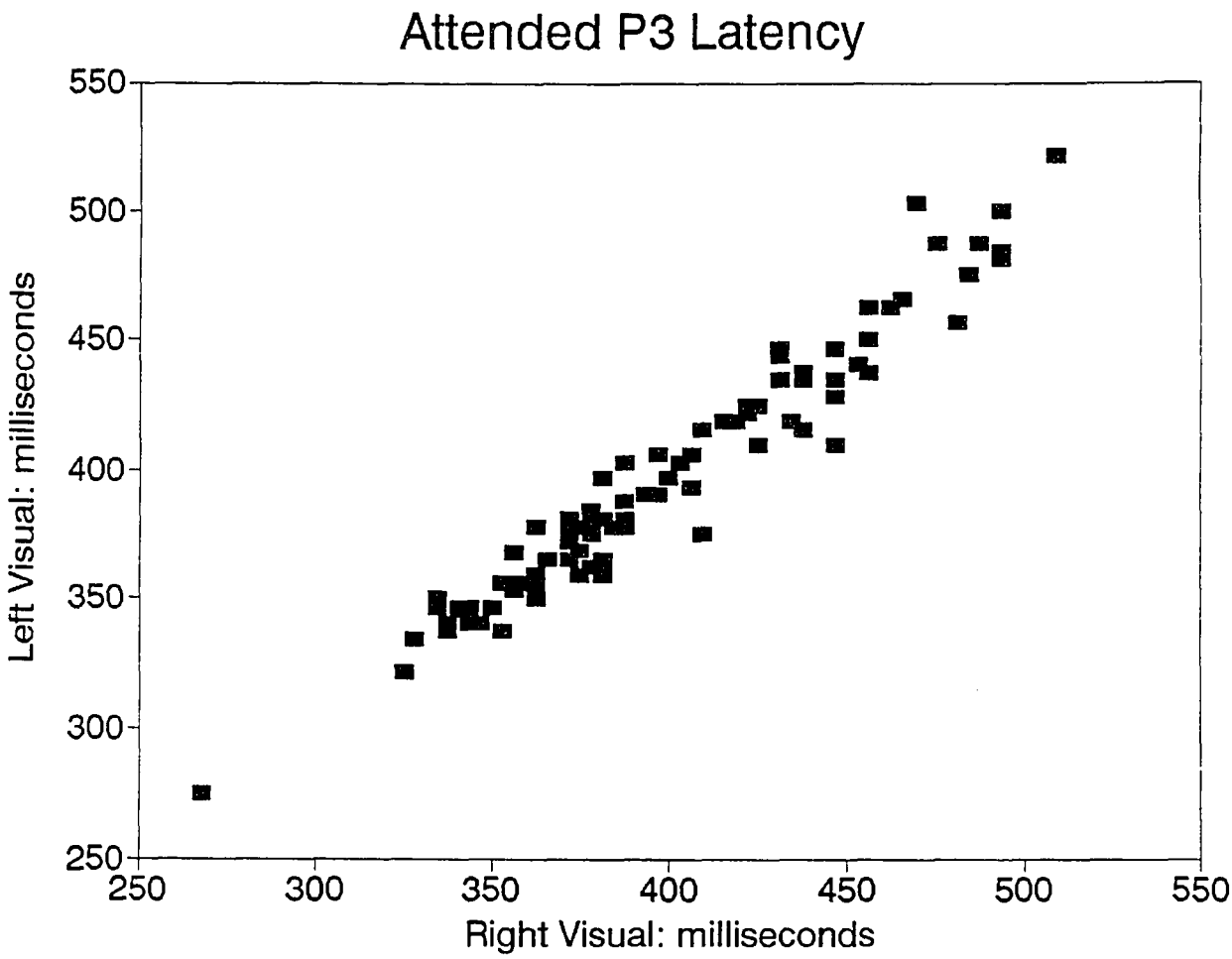
Figure 19. An evaluation of the split-half reliability of auditory P3 responses recorded from two sides of the subject's head simultaneously.




| | AUDITORY AMPLITUDE | |
|---|---|---|
| | Left | Right |
| n | 32 | 32 |
| minimum | 2.57 | 1.05 |
| maximum | 24.68 | 22.18 |
| mean | 8.40 | 8.17 |
| std. dev. | 5.93 | 5.77 |

PEARSON'S PRODUCT MOMENT CORRELATION: r = 0.971

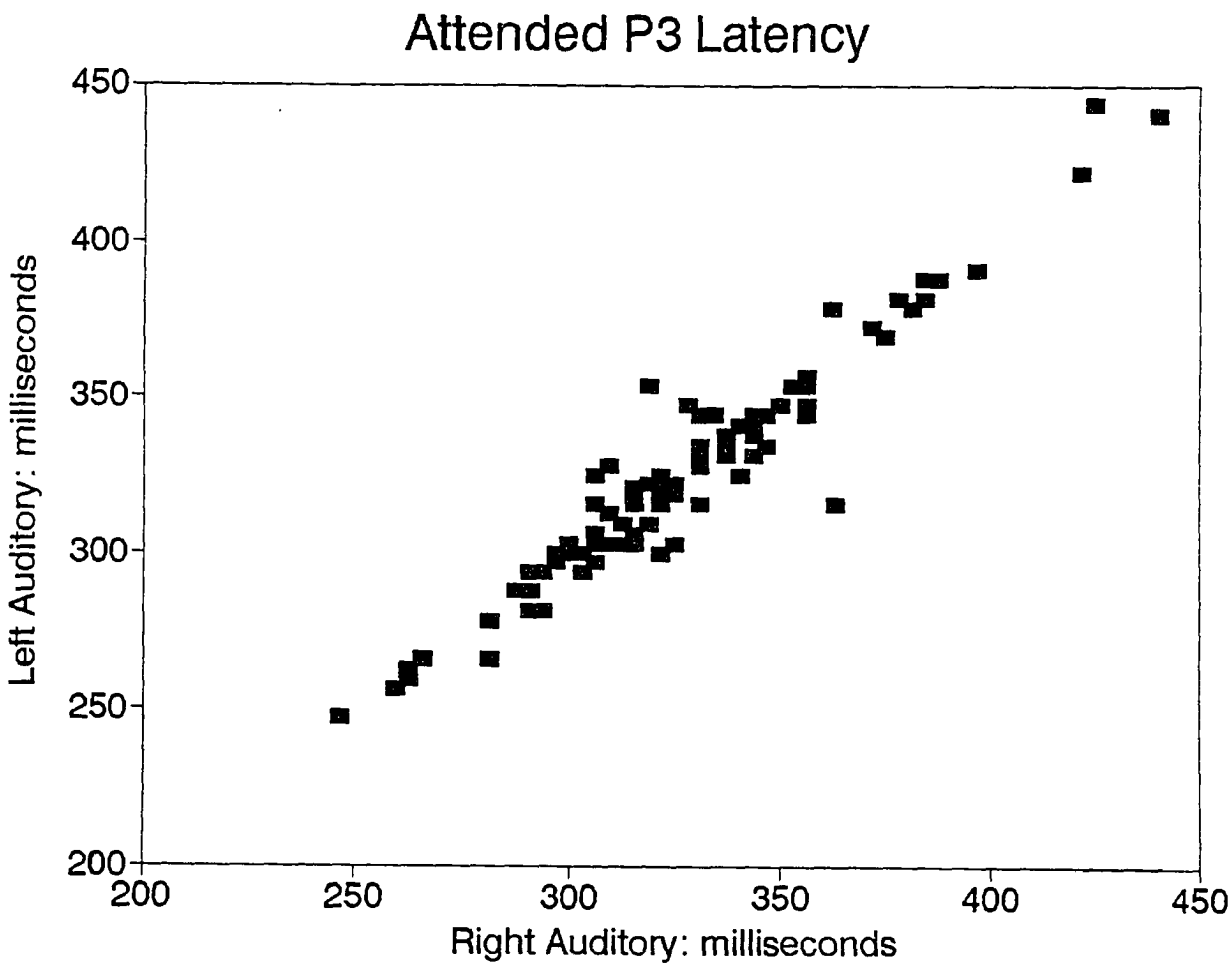
Figure 20. An evaluation of the split-half reliability of visual P3 responses recorded from two sides of the subject's head simultaneously.




| | VISUAL LATENCY | |
|---|---|---|
| | Left | Right |
| n | 32 | 32 |
| minimum | 284.87 | 284.37 |
| maximum | 450.00 | 497.32 |
| mean | 359.09 | 361.06 |
| std. dev. | 40.51 | 48.56 |

PEARSON'S PRODUCT MOMENT CORRELATION: r = 0.962

Figure 21. An evaluation of the split-half reliability of auditory P3 responses recorded from two sides of the subject's head simultaneously.




| | AUDITORY LATENCY | |
|---|---|---|
| | Left | Right |
| n | 32 | 32 |
| minimum | 231.25 | 231.25 |
| maximum | 501.32 | 521.87 |
| mean | 336.06 | 337.73 |
| std. dev. | 53.85 | 55.49 |

PEARSON'S PRODUCT MOMENT CORRELATION: r = 0.989

Conclusions. The reliability of the characteristics of P3 amplitude and P3 latency, to an attended rare stimulus, exceed the split-half reliability benchmark for exogenous potentials in both sensory modalities. Although the four reliabilities are all $r > 0.90$, which places them in the range generally agreed to be minimally acceptable for decisions about individuals, other knowledge deficits and technical limitations suggest that such use may still be premature. It was concluded that the data recorded by the methods described have excellent internal consistency, and that the split-half reliability is acceptable for research purposes.

## EXPERIMENT FOUR: PART TWO

### An Evaluation of the Test-Retest Reliability of Event-Related Potentials.

Test-retest methods assess the temporal stability of the measurement results by administering the test on one occasion and then giving a repeat administration on a second occasion. The similarity between the two scores indicates to what extent the test scores can be generalized from one situation to the next (Groth-Marnat, 1990).

One of the major difficulties with test-retest reliability is that the time interval between administrations can affect the results when assessing an unstable variable (e.g., anxiety). In general, test-retest methods are preferred when what is being measured is a relatively stable phenomenon. Test-retest is an inadequate assessment of reliability when a trait is highly variable, and/or when intervals between testing are fairly long.

The purpose of this investigation was to evaluate the test-retest reliability of event-related potentials over a short time interval, as the longitudinal study protocol necessitates two ERP tests being administered consecutively.

For both P3 amplitude and P3 latency:

Ho: Trial-1 = Trial-2

Ha: Trial-1 differs from Trial-2

Subjects. The sample consisted of 20 healthy normal human volunteers solicited from among the spring 1992 University of Alaska Fairbanks undergraduate psychology courses, who were participating in a lengthy test-retest evaluation (10 consecutive tests) of auditory ERPs. For the purpose of this analysis, only the initial two recordings were considered. Of this group, data from 17 subjects was available (3 had early technical difficulties with recording and were excluded); 14 were female (ages 19-33 years, M = 21.85 yrs., STD = 3.93 yrs.) and 3 were male (ages 18-28 years, M = 21.28 yrs., STD = 3.19 yrs.).

Methods. All participated in event-related potential recording during an auditory oddball detection paradigm using the methods previously described. Each recording lasted 4 minutes, with a 2-minute rest between recording epochs while data was saved to computer disk. The entire test-retest data for this purpose was acquired within ten minutes.

Results. The P3 amplitude, recorded from each side of the head separately, is graphically compared in Figure 22. An evaluation of the test-retest reliability of the P3 amplitude is shown in Table 6. As can be seen, there is no

Figure 22. An evaluation of the auditory P3 amplitude in two consecutive ERP tests, recording separately, yet simultaneously, from two sides of the subject's head.

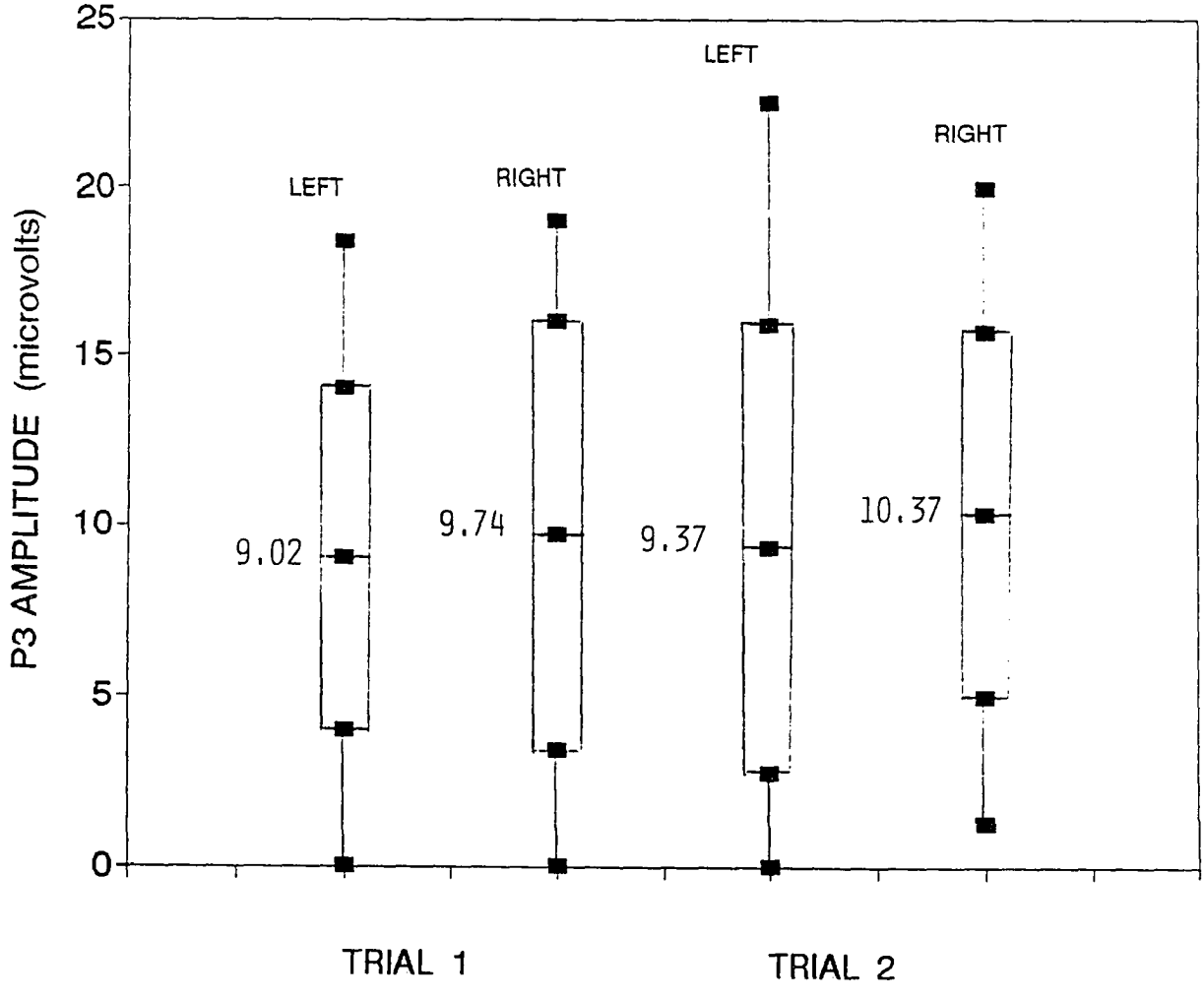


Table 6. An evaluation of ERP test-retest reliability.

| | Test #1 | | | | Test #2 | | | |
|---|---|---|---|---|---|---|---|---|
| | L-amp | R-amp | L-lat | R-lat | L-amp | R-amp | L-lat | R-lat |
| min | 0.001 | 0.001 | 253.12 | 259.37 | 0.001 | 1.250 | 262.50 | 262.50 |
| max | 18.430 | 19.060 | 350.00 | 343.75 | 22.500 | 20.000 | 368.75 | 334.37 |
| mean | 9.022 | 9.739 | 306.79 | 307.90 | 9.372 | 10.379 | 312.13 | 303.67 |
| StdDv | 5.022 | 6.304 | 24.26 | 23.38 | 6.603 | 5.394 | 26.26 | 20.73 |

amplitude in microvolts, latency in milliseconds

Left Auditory Amplitude:
overall mean = 9.197 overall standard deviation = 5.779
pooled within groups standard deviation = 5.866
t- statistic = - 0.174 p = 0.863

Conclusion: There is no significant difference in the results obtained from the left side of the head between the two tests performed sequentially.

Right Auditory Amplitude:
overall mean = 10.059 overall standard deviation = 5.787
pooled within groups standard deviation = 5.867
t- statistic = - 0.318 p = 0.752

Conclusion: There is no significant difference in the results obtained from the right side of the head between the two tests performed sequentially.

Left Auditory Latency:
overall mean = 309.465 overall standard deviation = 25.042
t- statistic = - 0.615 p = 0.543

Conclusion: There is no significant difference in the results obtained from the left side of the head between the two tests performed sequentially.

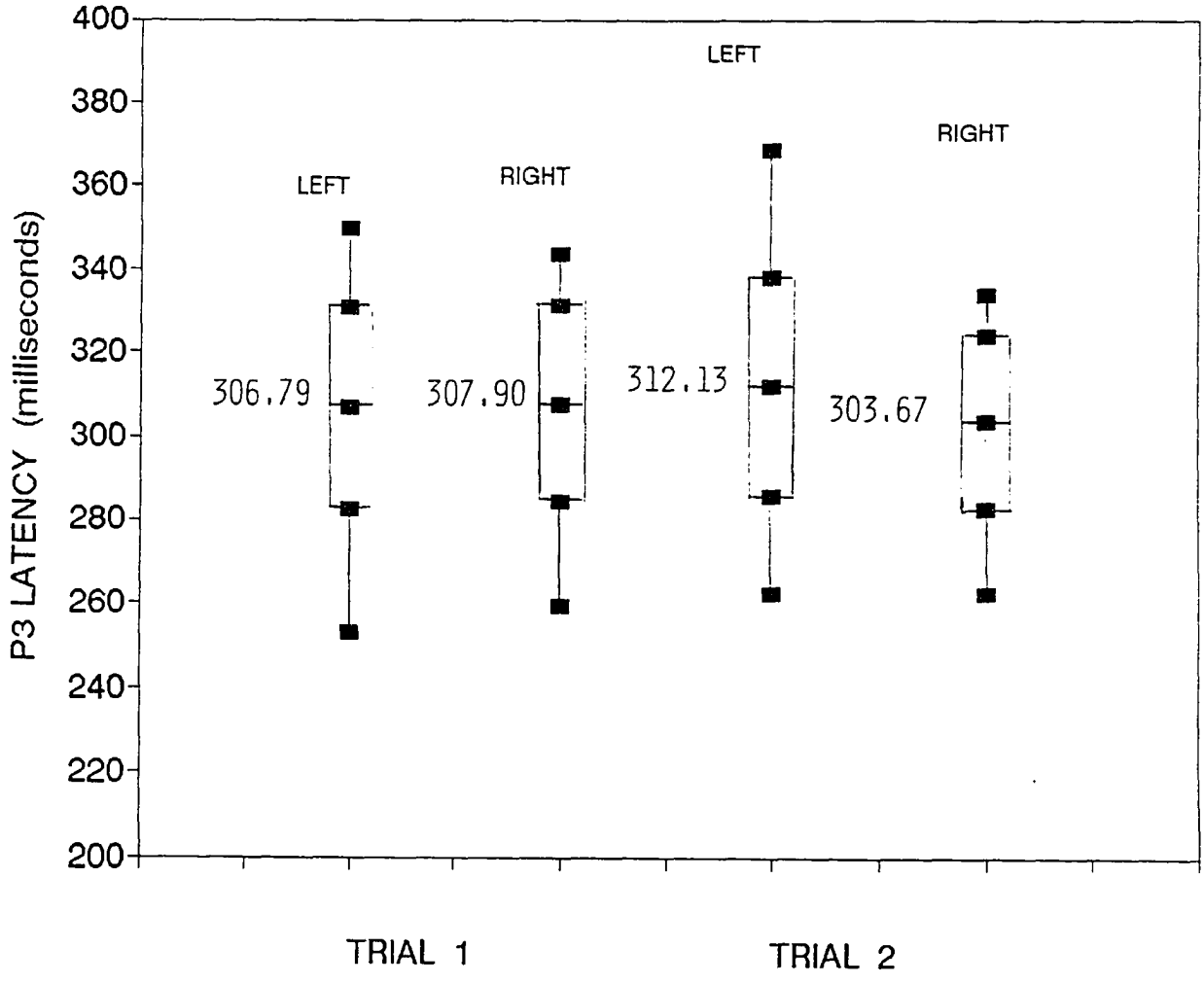
Right Auditory Latency:
overall mean = 308.788 overall standard deviation = 22.870
t- statistic = - 0.558 p = 0.581

Conclusion: There is no significant difference in the results obtained from the right side of the head between the two tests performed sequentially.

significant difference (left, $p = 0.863$; right, $p = 0.752$) in the P3 amplitude obtained when two tests are given within ten minutes of each other.

The P3 latency, recorded from each side of the head separately, is shown in Figure 23. An evaluation of the test-retest reliability of P3 latency is shown in Table 6. As can be seen, there is no significant difference (left, $p = 0.543$; right, $p = 0.581$) in the P3 latency obtained when two tests are given within ten minutes of each other.

Figure 23. An evaluation of the auditory P3 latency in two consecutive ERP tests, recording separately, yet simultaneously, from two sides of the subject's head.



Conclusions. The P3 amplitude demonstrated a high degree of variability, as evidenced by the wide range of values observed (0.001 - 22.5 microvolts). However, there was no significant difference in the auditory P3 amplitude, or in the auditory P3 latency, in the results from two tests given consecutively during a ten-minute interval.

It was concluded that the currently used ERP methods produce data which demonstrate adequate test-retest reliability when administered over short time intervals. It is also concluded that the phenomenon measured by P3 amplitude is most likely unstable, given the wide range of responses, and, therefore, test-retest methods may not be appropriate for longer time intervals such as monthly testing (see experiment five).

## EXPERIMENT FOUR - PART THREE

### An Evaluation of the Parallel Forms Reliability of Event-Related Responses Recorded in Two Sensory Modalities.

The parallel forms method of assessing a test's reliability avoids many of the instabilities associated with the test-retest method. In the parallel forms method, the trait of interest is measured twice, with two similar forms of the test. The reliability coefficient between the two forms represents the degree of similarity in test results. When the two similar forms are given one immediately after the other, the resultant reliability coefficient is more a measure of correlation between forms rather than between occasions (Groth-Marnat, 1990).

The purpose of this investigation was to evaluate the similarity in ERP response data obtained using two similar forms (auditory and visual) of the oddball detection paradigm and identical recording methodology.

Ho: parallel forms reliability > 0.75

Ha: parallel forms reliability < 0.75

Subjects. This investigation used the same subjects as were used in the split-half assessment. The visual ERP immediately followed the auditory ERP.

Methods. The methods were the same as previously described. Only the P3 portion of the ERP data recorded as a response to a target stimulus was considered.

Results. Auditory and visual P3 amplitude, recorded from the right side of the subject's head, are graphically compared in Figure 24. Pearson's product moment correlation for right auditory vs right visual P3 amplitude showed r = 0.654.

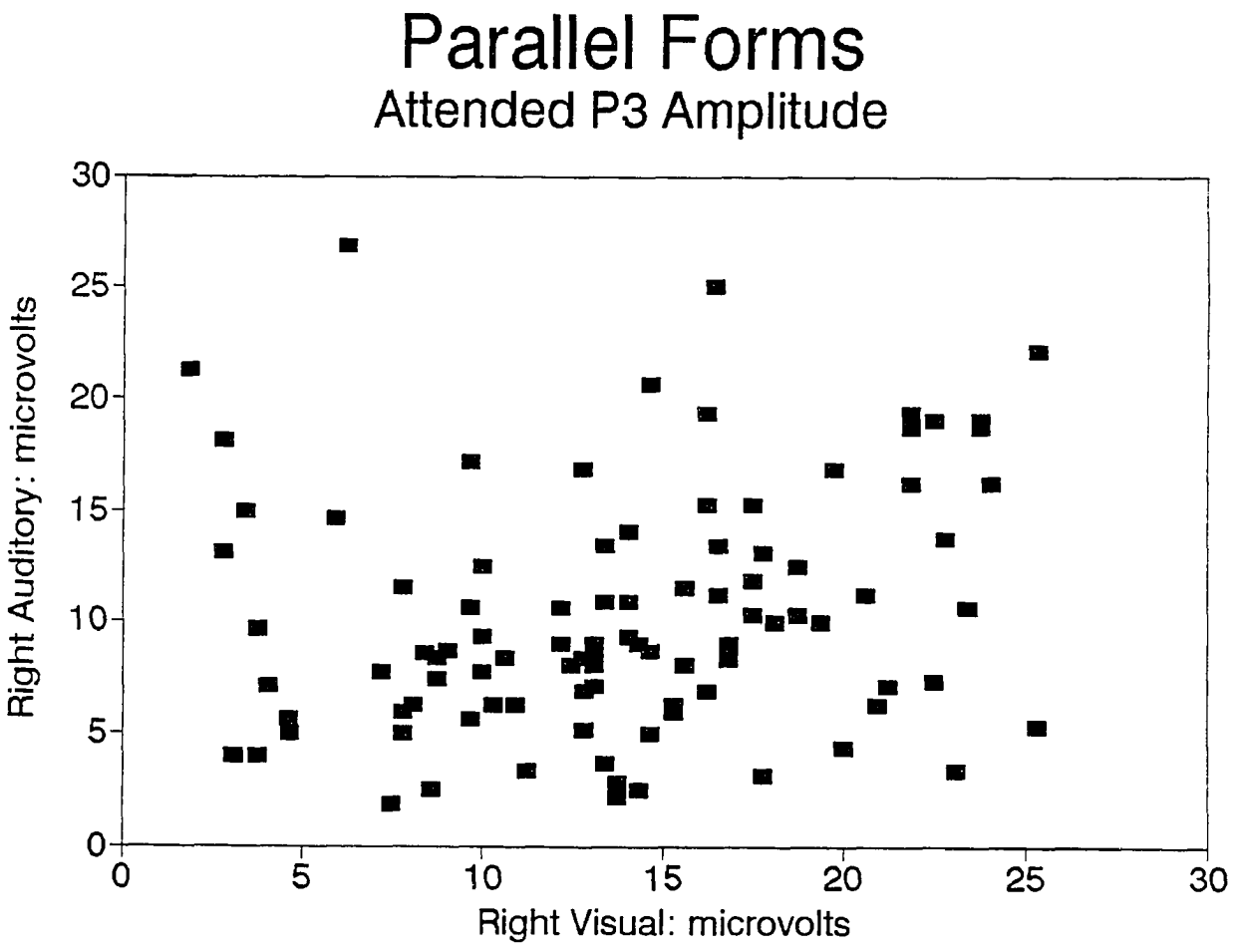
Auditory and visual P3 amplitude, recorded from the left side of the subject's head, are graphically compared in Figure 25. Pearson's product moment correlation for left auditory vs left visual P3 amplitude showed r = 0.558.

Auditory and visual P3 latency, recorded from the right side of the subject's head, are graphically compared in Figure 26. Pearson's product moment correlation for right auditory vs right visual P3 latency showed r = 0.013.

Auditory and visual P3 latency, recorded from the left side of the subject's head, are graphically compared in Figure 27. Pearson's product moment correlation for left auditory vs left visual P3 latency showed r = -0.412.

Conclusions. Although the linear relationship is stronger for P3 amplitude than for P3 latency, the reliability of the responses recorded from the same side of a subject's head using two sensory modalities did not reach the benchmark

Figure 24. Evaluation of the parallel form reliability of ERPs in two sensory modalities recorded from the same side of the subject's head.

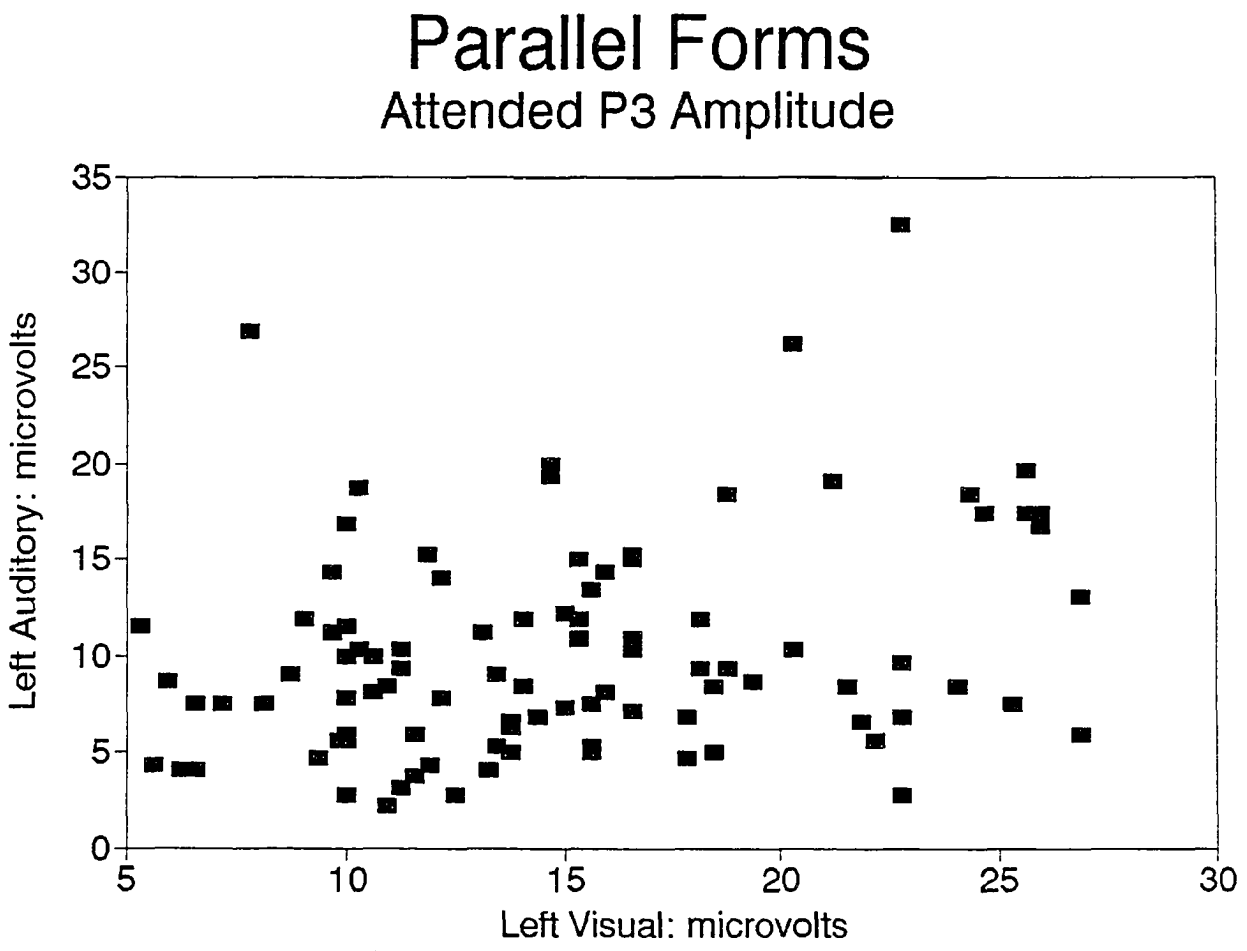



AMPLITUDE: Right Hemisphere

| | Auditory | Visual |
|---|---|---|
| n | 32 | 32 |
| minimum | 1.05 | 2.03 |
| maximum | 22.18 | 23.75 |
| mean | 8.17 | 9.08 |
| std. dev. | 5.77 | 5.52 |

PEARSON'S PRODUCT MOMENT CORRELATION r = 0.654

Figure 25. Evaluation of the parallel form reliability of ERPs in two sensory modalities recorded from the same side of the subject's head.

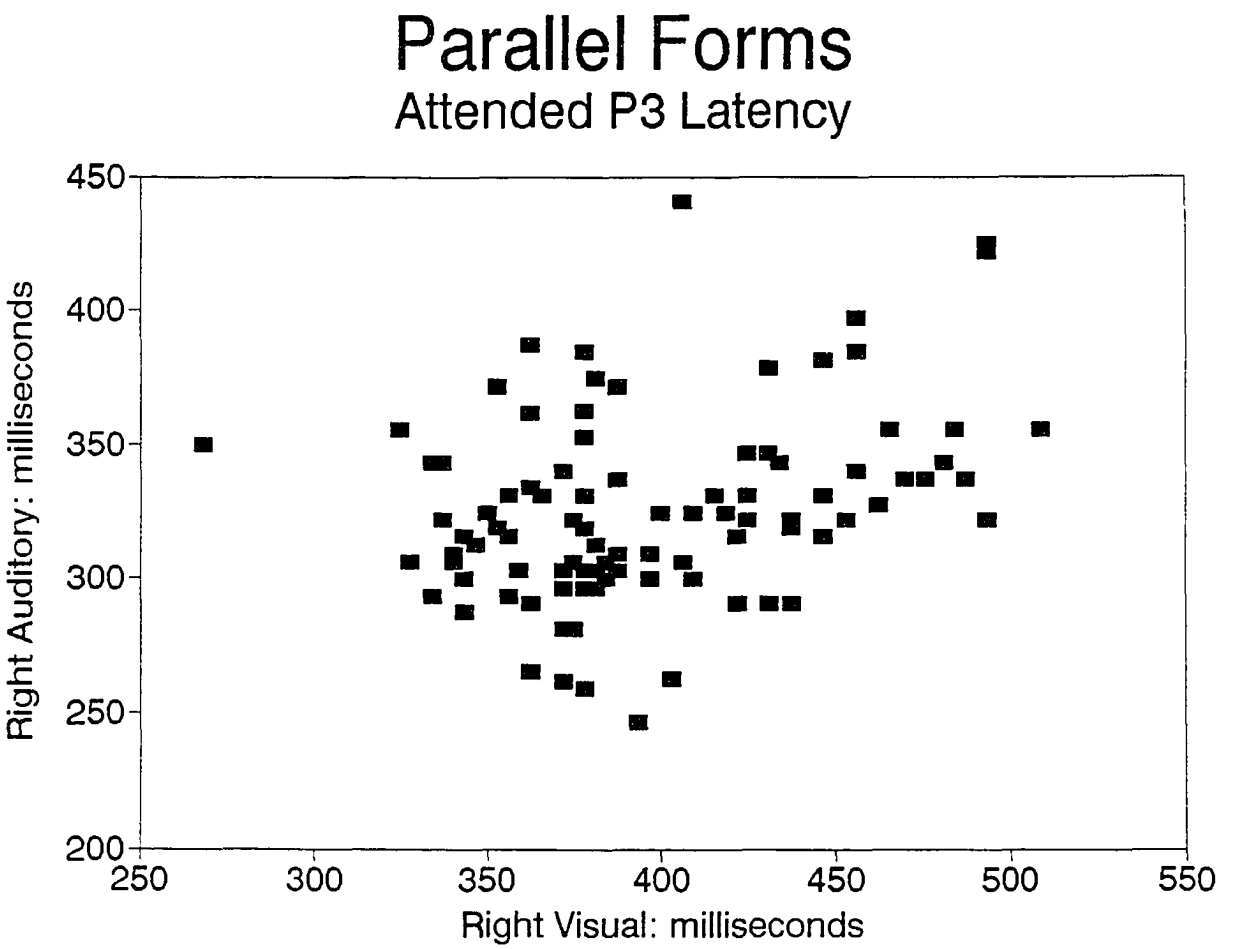



AMPLITUDE: Left Hemisphere

| | Auditory | Visual |
|---|---|---|
| n | 32 | 32 |
| minimum | 2.57 | 1.87 |
| maximum | 24.68 | 27.84 |
| mean | 8.40 | 8.84 |
| std. dev. | 5.93 | 5.82 |

PEARSON'S PRODUCT MOMENT CORRELATION r = 0.558

Figure 26. Evaluation of the parallel form reliability of ERPs in two sensory modalities recorded from the same side of the subject's head.

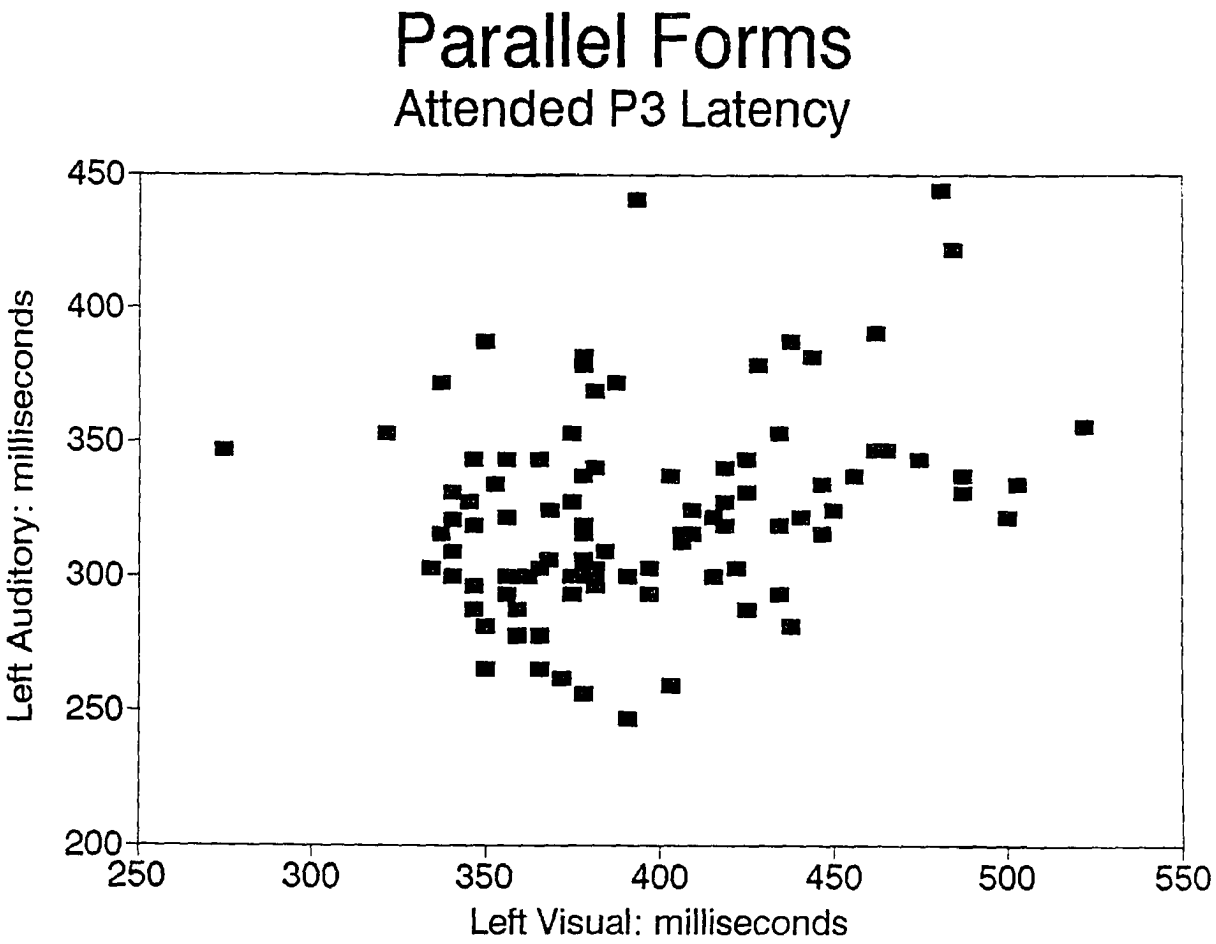



LATENCY: Right Hemisphere

| | Auditory | Visual |
|---|---|---|
| n | 32 | 32 |
| minimum | 231.25 | 284.37 |
| maximum | 521.87 | 497.32 |
| mean | 337.73 | 361.06 |
| std. dev. | 55.49 | 48.56 |

PEARSON'S PRODUCT MOMENT CORRELATION r = 0.013

Figure 27. Evaluation of the parallel form reliability of ERPs in two sensory modalities recorded from the same side of the subject's head.




LATENCY: Left Hemisphere

| | Auditory | Visual |
|---|---|---|
| n | 32 | 32 |
| minimum | 231.25 | 284.87 |
| maximum | 501.32 | 450.00 |
| mean | 336.06 | 359.09 |
| std. dev. | 53.85 | 40.61 |

PEARSON'S PRODUCT MOMENT CORRELATION r = - 0.412

reported for exogenous potentials ($r > 0.75$), and did not reach the level generally accepted for research purposes ($r > 0.70$).

It is unlikely that the differences observed are due to the unreliability of the ERP measure, given the excellent split-half reliability and adequate test-retest reliability already demonstrated. Given that the two oddball detection protocols differ only in the sensory modality used, it is more likely that the differences observed represent true differences between the two test forms, auditory and visual.

It is concluded, therefore, that the two forms are not parallel. A large auditory P3 amplitude is not strongly associated with a large visual P3 amplitude, and similarly, a short auditory P3 latency is not strongly associated with a short visual P3 latency. This observation differs from the findings of Squires, Donchin, Squires, and Grossberg, (1977) who concluded that "the auditory and visual P300's can be considered to be equivalent components" (pg. 308). The results of the present investigation suggest that, in the sample from the subarctic population, the responses differ between the two sensory modalities. Therefore, the two forms of data obtained need to be evaluated independently.

## EXPERIMENT FOUR - PART FOUR

### An Evaluation of the Comparability of Results Obtained Recording With Unlinked Mastoids or Linked Mastoids.

The newer neurodiagnostic equipment, such as that used in the present investigation, offers the capability of measuring the activity recorded from each side of the head separately, yet simultaneously. This raises the question of comparability of results obtained in this manner, with unlinked mastoids, to results published in the ERP literature. Much of the early ERP work, such as during the 1960's or 1970's, was technologically limited to a choice between one side of the head or the other, or using a linked mastoid montage.

The purpose of this investigation was to evaluate the comparability of these results, using an unlinked mastoids recording montage, to published results from other laboratories which use a linked mastoid method.

Ho: unlinked results = linked results.

Ha: unlinked results differ from linked results.

experiment-wise alpha = 0.05.

Subjects. Volunteers were solicited from among the fall, 1992 University of Alaska Fairbanks undergraduate psychology

courses. A total of 14 healthy normal adults volunteered, of which 10 were female (ages 18 - 34 years, M = 20.8 yrs., STD = 2.57 yrs.) and 4 males (ages 18 - 32 years, M = 22.5 yrs., STD = 3.49 yrs.). All subjects were right-handed.

Methods. Seven subjects were tested in the auditory oddball detection paradigm, in two consecutive trials entirely completed within ten minutes. Seven subjects were tested in the visual oddball detection paradigm, in two consecutive trials, entirely completed within ten minutes. The order of testing, linked or unlinked, was randomized across subjects within sensory modality.

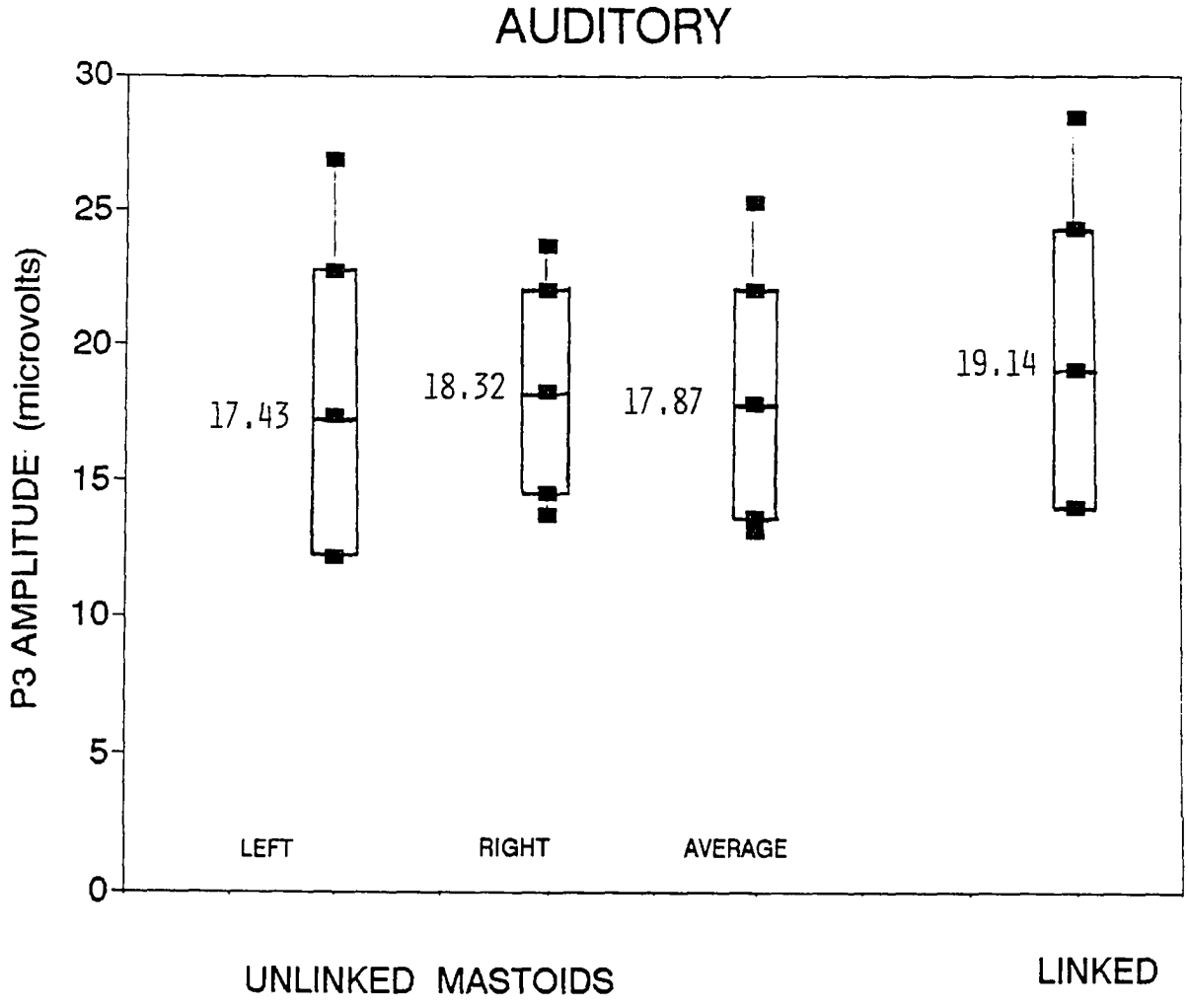
Data were pooled, within recording location, prior to performing paired samples t-test evaluation. The average value of the two unlinked sites was also compared to the results from linked mastoids.

Results.

| | Paired-Samples | | |
|---|---|---|---|
| AMPLITUDE: | Unlinked-Left | Unlinked-Right | Unlinked-Avg. |
| Linked | t = 0.330<br>p = 0.746 | t = 0.193<br>p = 0.849 | t = 0.281<br>p = 0.783 |
| LATENCY: | | | |
| Linked | t = 0.772<br>p = 0.453 | t = 0.453<br>p = 0.657 | t = 0.666<br>p = 0.516 |

The auditory P3 amplitudes obtained (means range = 17.43 - 19.14 microvolts) are graphically presented in Figure 28. The visual P3 amplitudes obtained (means range = 14.87 - 15.58 microvolts) are graphically compared in Figure

Figure 28. Evaluation of the results obtained when recording with unlinked mastoids as compared to recording with linked mastoids.



29. As can be seen in the paired-samples table, there were no significant differences detected in P3 amplitude, whether using linked or unlinked mastoid recording protocols.

The auditory P3 latency obtained (means range = 307.13 - 308.49 milliseconds) are graphically compared in Figure 30. The visual P3 latency obtained (means range = 369.13 - 380.46 milliseconds) are graphically compared in Figure 31. As can be seen in the paired-samples table, there were no significant differences in the results obtained, whether using linked or unlinked mastoid recording protocols.

Figure 29. Evaluation of the results obtained when recording with unlinked mastoids as compared to recording with linked mastoids.

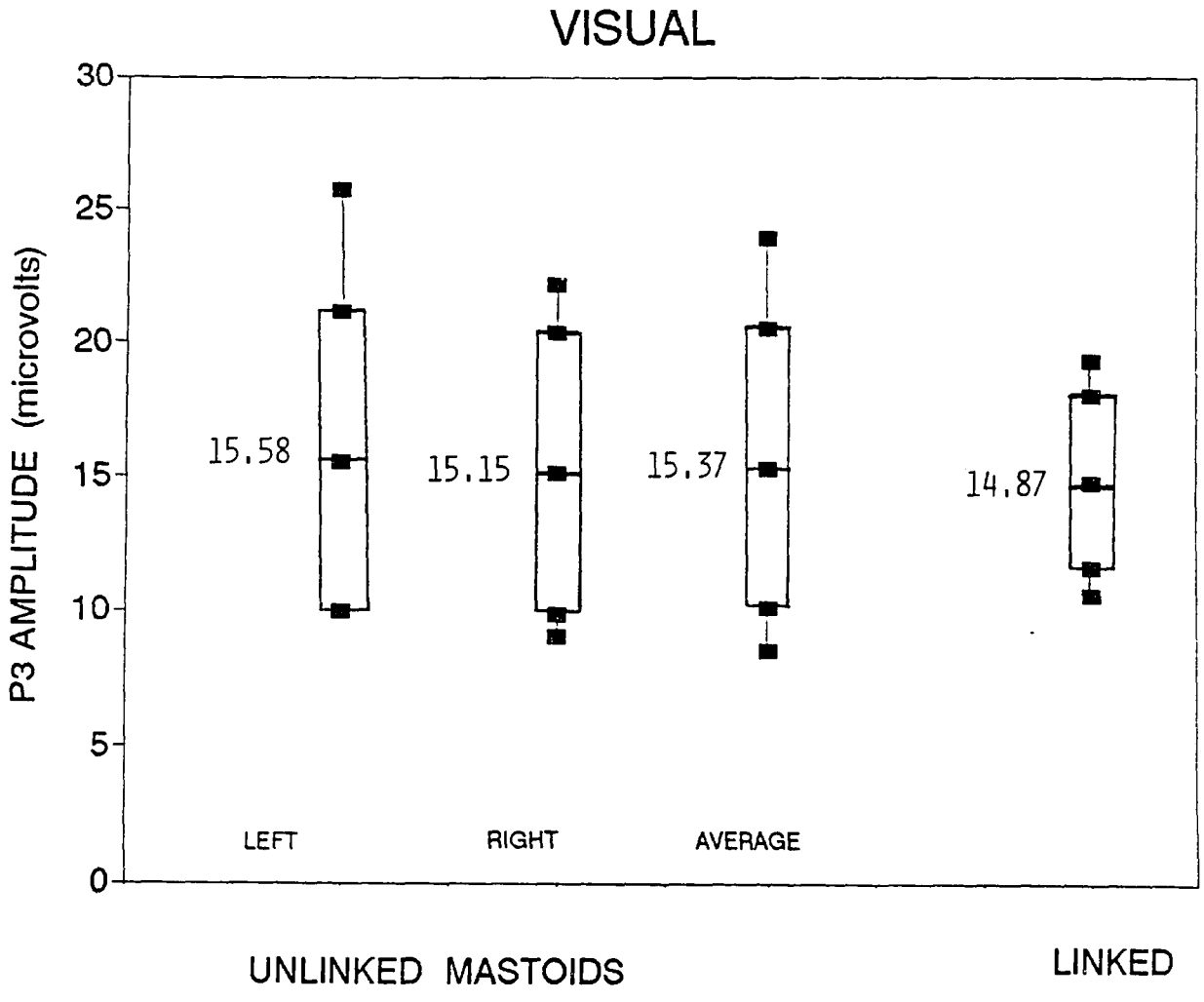


Figure 30. Evaluation of the results obtained when recording with unlinked mastoids as compared to recording with linked mastoids.

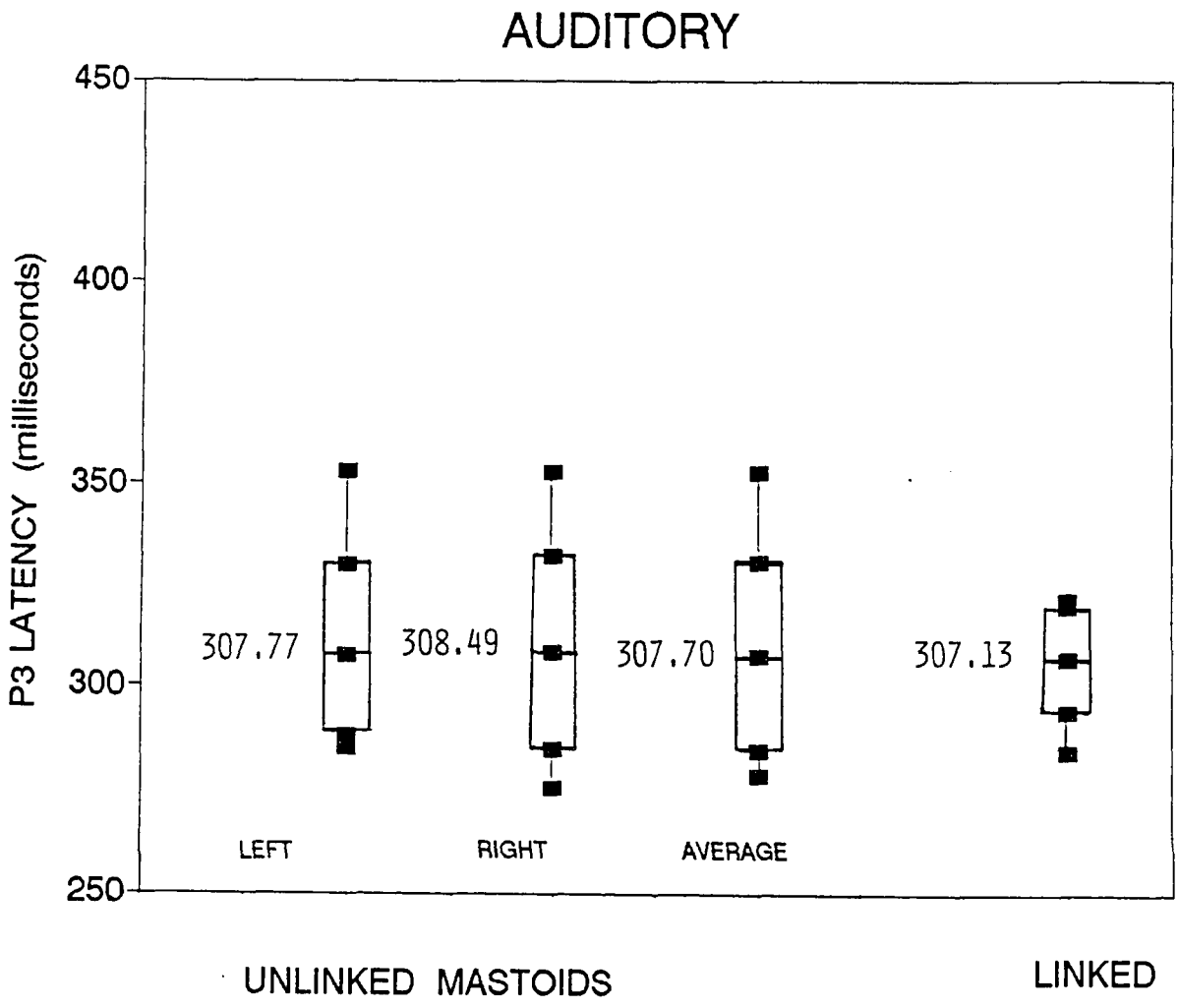
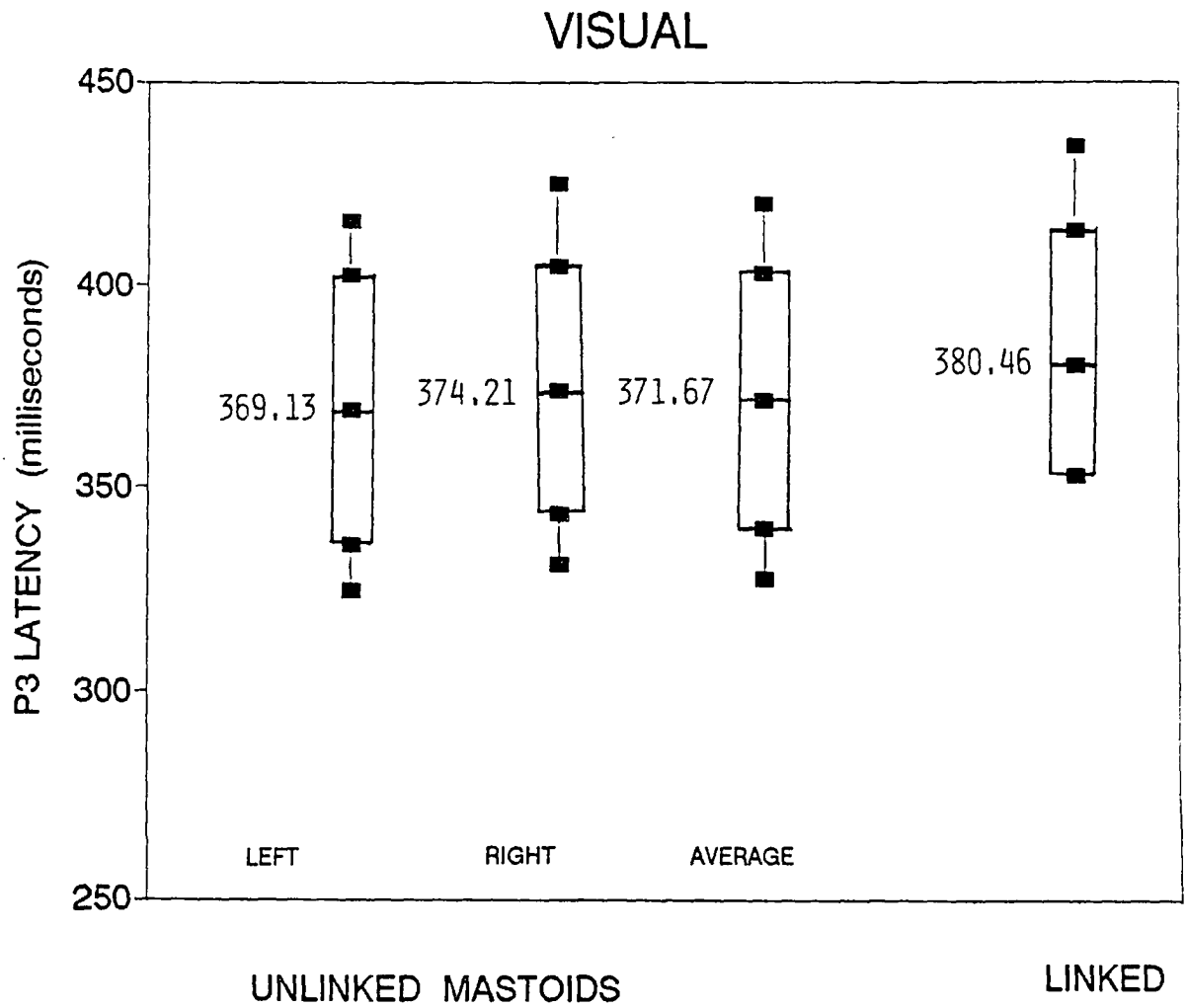


Figure 31. Evaluation of the results obtained when recording with unlinked mastoids as compared to recording with linked mastoids.



Conclusions. The results obtained by the methods described, recording with unlinked mastoids, are not significantly different from results obtained by recording with linked mastoids. It was concluded that results obtained by the methods described can be interpreted with respect to results published in the ERP literature, even though those reports may use a linked mastoid recording protocol. However, it is acknowledged that factors other than the recording montage may limit comparability and interpretation of the results.

# EXPERIMENT FIVE

## Longitudinal Evaluation of the Variability of Event-Related Brain Potentials Recorded from Normal Humans Living at High Latitude.

Bush, A. M., & Geist, C. R.

## EXPERIMENT FIVE

### Longitudinal Evaluation of the Variability of Event-Related Brain Potentials Recorded from Normal Humans Living at High Latitude.

The U. S. Arctic Research Plan (Interagency Arctic Research Policy Committee, 1987) called for studies to investigate factors affecting human performance at high latitude. Anderson et al., (1984) reported seasonal changes in the EEG of humans at 69 degrees north latitude in a longitudinal study recording four times, from the same normal human subjects. Two years later Duncan and Rosenthal (1986) reported event-related potential changes with applied phototherapy in a group of SAD patients sampled twice. Recent reports (Deldin, Duncan, & Miller, 1989a; 1989b) using single-trial sampling concluded that P300 varies with light and shows a seasonal variability. However, the longterm stability of ERP responses has not been demonstrated, largely due to the rarity of longitudinal studies in the ERP literature.

Three purposes of the present investigation were to first, study a group of normal humans living at high latitude longitudinally to determine whether seasonal changes, such as reported by Anderson et al. (1984) using

EEG, were similarly observed in the ERP recordings. The second purpose was to determine if any seasonal changes observed in the ERP recordings could be attributed to the natural variation of significant environmental factors experienced at high latitude (see experiment seven for photoperiod and experiment eight for geomagnetic field variation). The third purpose was to describe a baseline of ERP variability in normal subjects, under high latitude conditions, as a necessary prerequisite to future work studying factors which affect human performance at high latitude.

Ho: ERP characteristics do not vary from month to month.

Ha: At least one ERP characteristic varies.

Subjects. A sample of human subjects was invited to volunteer for the longitudinal study of ERP variability of normal humans living at high latitude. A volunteer was judged to be a suitable subject provided he/she was: free of SAD or other neurobehavioral dysfunctional symptoms, gainfully employed or successfully enrolled in school, possessed functionally adequate hearing and vision bilaterally, had an adequate command of the English language in order to give informed consent/assent and to follow task instructions, demonstrated the ability to capably perform the sensory discrimination tasks requested during a training/screening trial, and reported himself/herself to be

free of such substances as marijuana, cocaine, (Koppell, et al., 1978) and so forth. Initially, twelve suitable subjects committed to the longterm project, two never began, and two withdrew after the initial testing, leaving eight to complete the full 12 consecutive months of ERP testing.

The subjects were all volunteers who were fully informed of all details of the project prior to their consent. Subjects were free at all times to ask questions and could withdraw at any time. Because of the longterm (12 consecutive months) committment of the uncompensated volunteers, and because of necessary school/work/family obligations, subjects were free to choose the day of the month, and time of the day, which was most convenient for them to participate in ERP testing. All subjects were tested during their normally diurnally active period (between 8 a.m. and 4 p.m.), and reported themselves to be awake and alert at the time of testing.

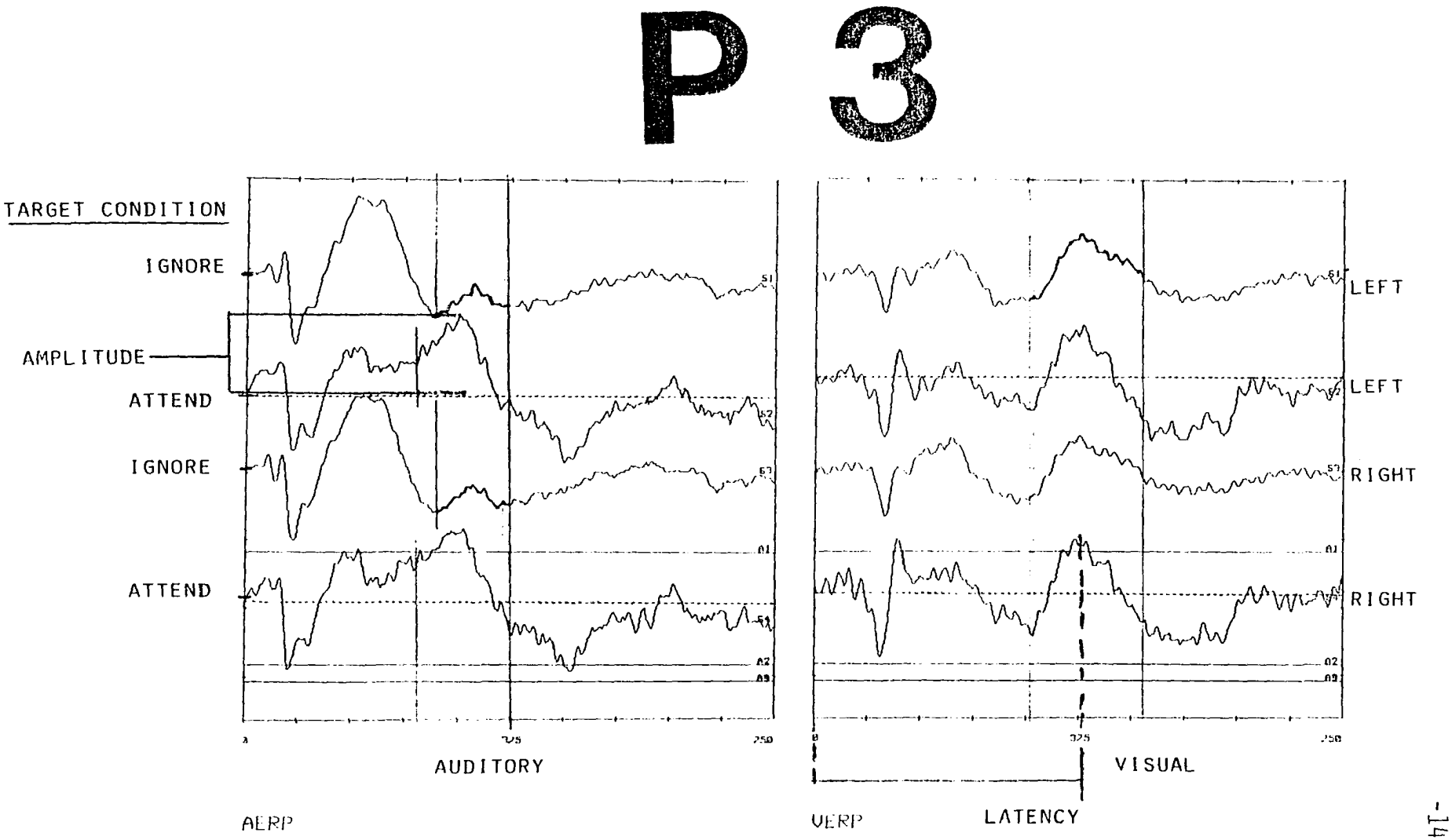
The eight subjects who completed the full year of monthly ERP testing were all right-handed Caucasian residents of the Alaskan subarctic. Ages were converted to decimal years by dividing the number of months past their birthmonth by 12. For example, for a person born in November, the initial June starting age would be XX years + 07/12, or XX.58 years. Each subject's age was advanced by 01/12 (0.083) year at each subsequent month of testing. The group consists of a cluster of 3 children (starting ages 9.75, 11.75 and 13.75 years), a cluster of 3 young adults

(starting ages 21.00, 26.58 and 32.00 years), and a cluster of 2 older adults (starting ages 39.58 and 45.66 years). Of these eight subjects, four were female (starting ages 9.75, 21.00, 32.00 and 39.58 years) and four were male (starting ages 11.75, 13.75, 26.58 and 45.66 years).

Of the eight, four are biologically related (parent and 3 children), the remaining four are not related. The heritability of ERP characteristics, per se, has not been determined. However, ERPs are being employed experimentally to determine whether certain of the ERP characteristics might be clinically useful markers in such heritable conditions as Huntington's chorea (Lawson, Barrett, Kriss, & Halliday, 1984; Rosenberg, Nudleman, & Starr, 1985), alcoholism (Whille, Parker, & Noble, 1988) and Charcot-Marie-Tooth hereditary neuropathy (Bird, & Griep, 1981).

Data. The longitudinal study group participated in 12 consecutive months of ERP testing in both the auditory and visual oddball detection paradigms, according to the laboratory methods previously described. The ERP characteristics included in the present investigation were the amplitude and latency of the P3 portion of the waveforms in response to an attended rare target, recorded simultaneously, but separately, from both the left and right sides of a subject's head, during first an auditory then a visual oddball detection procedure (Figure 32). The data

FIGURE 32. ONLY ATTENDED PORTION OF P3 WAVEFORM WAS FORMALLY ANALYZED.



obtained from all subjects was plotted separately for each sensory modality and ERP characteristic across 12 months time: auditory P3 amplitude (Figure 33), visual P3 amplitude (Figure 34), auditory P3 latency (Figure 35) and visual P3 latency (Figure 36). The remaining ERP characteristics (attended and ignored N1, P2, N4 and ignored P3) are graphically depicted in Appendix B, in a similar manner.

Design. The methods result in 96 cells of ERP data:

8 subjects x 2 sensory modes (auditory, visual) x 2 hemispheres (left, right) x 12 months x 2 ERP characteristics (amplitude, latency).

A descriptive summary of the P3 data obtained is shown for 48 cells of attended P3 amplitude (Table 7) and 48 cells of attended P3 latency (Table 8).

Normality. The data distribution was assessed for normality, at the cell level, using SAS/STAT Version 6.0 Procedure Univariate to perform the Shapiro-Wilk test of normality at alpha = 0.05. The Shapiro-Wilk W-stat has been shown to have excellent power to detect departures from normality (Zar, 1984). The W-stat corresponding to the 96 cells of ERP data are shown for attended P3 amplitude (Table 9) and attended P3 latency (Table 10).

Six of the 96 cells were observed to be not normally distributed using the Shapiro-Wilk test. However, since the

Figure 33. Variability of the attended auditory P3 amplitude from the same subjects over 12 calendar months.

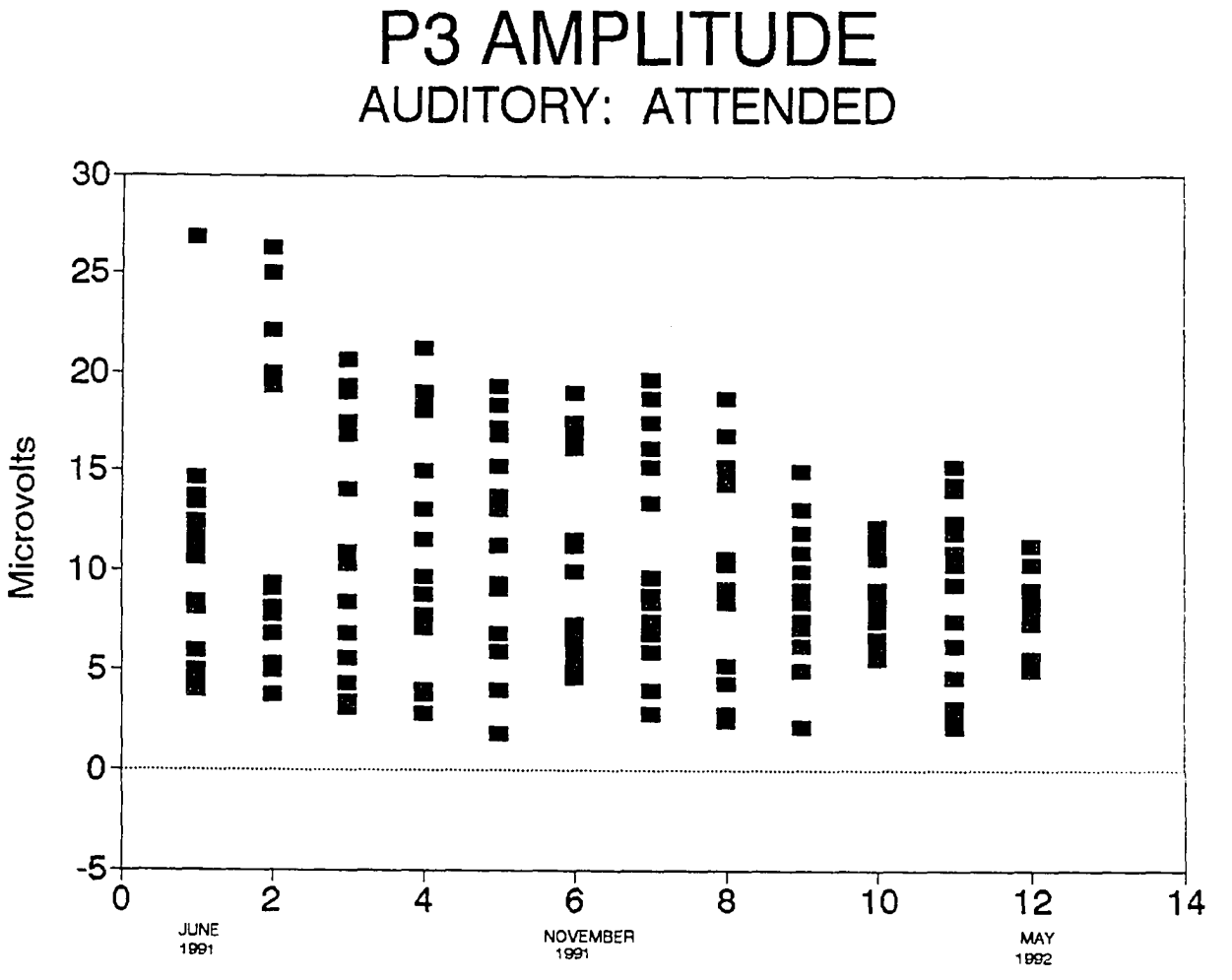


Figure 34. Variability of the attended visual P3 amplitude from the same subjects over 12 calendar months.

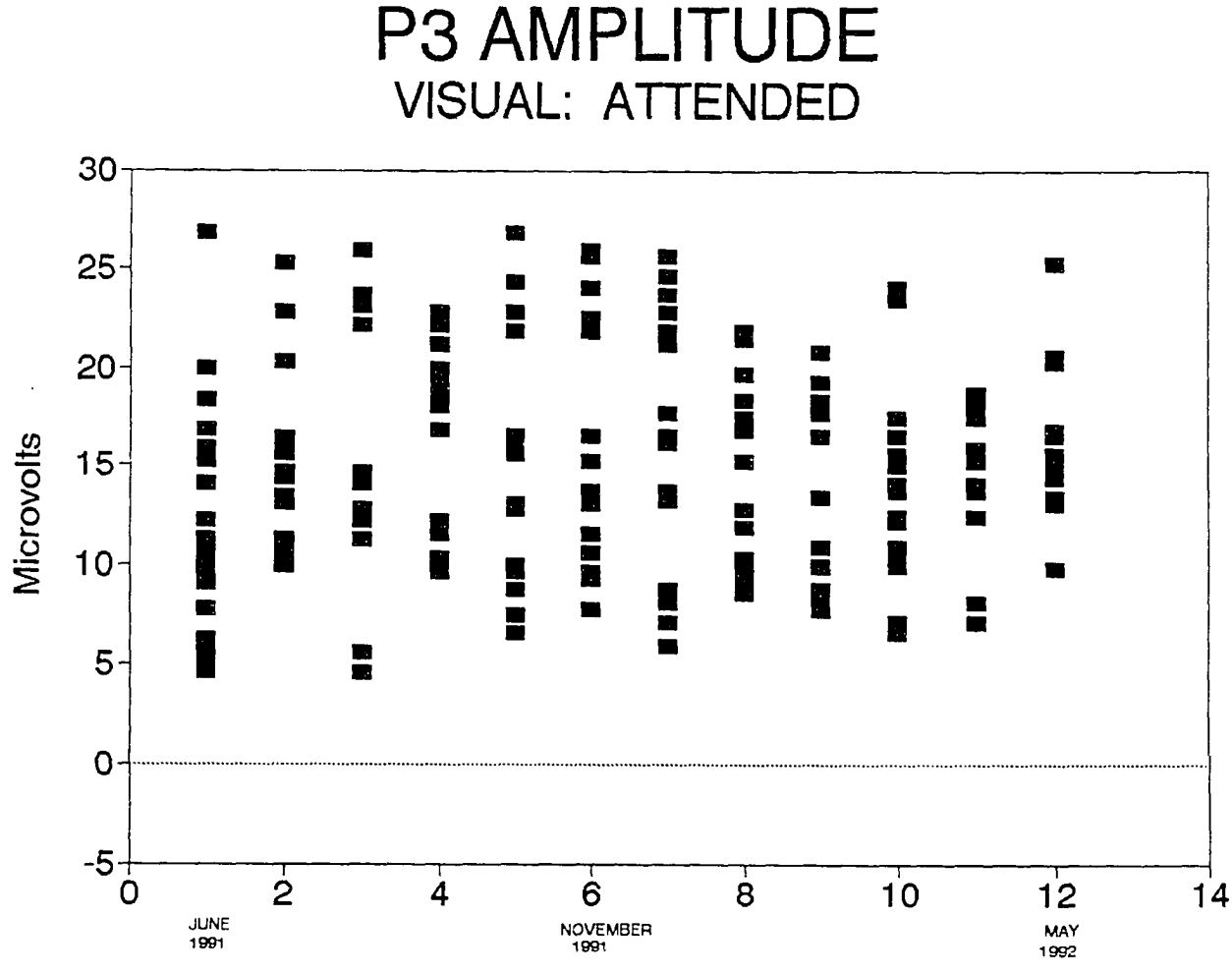


Figure 35. Variability of the attended auditory P3 latency from the same subjects over 12 calendar months.

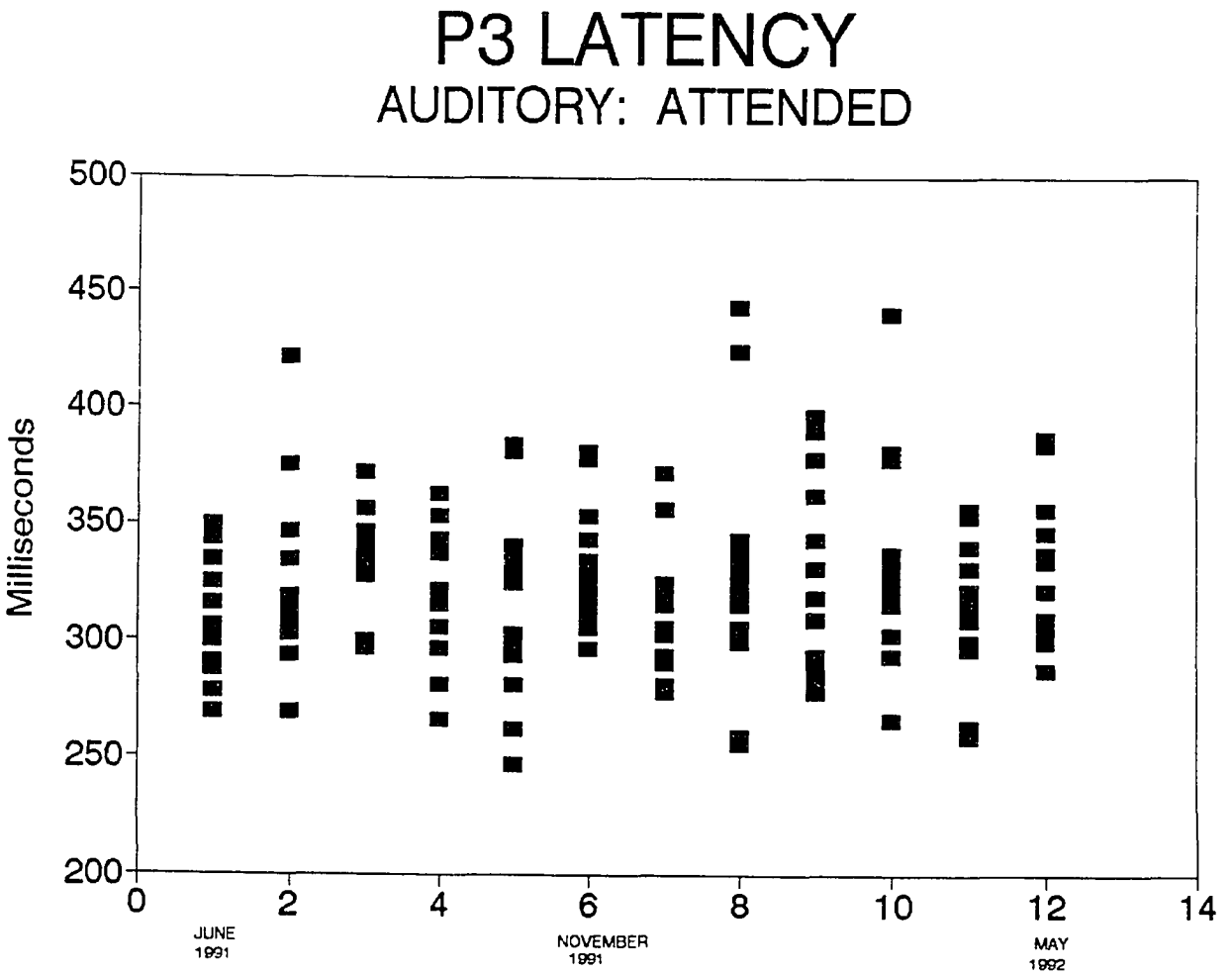


Figure 36. Variability of the attended visual P3 latency from the same subjects over 12 calendar months.

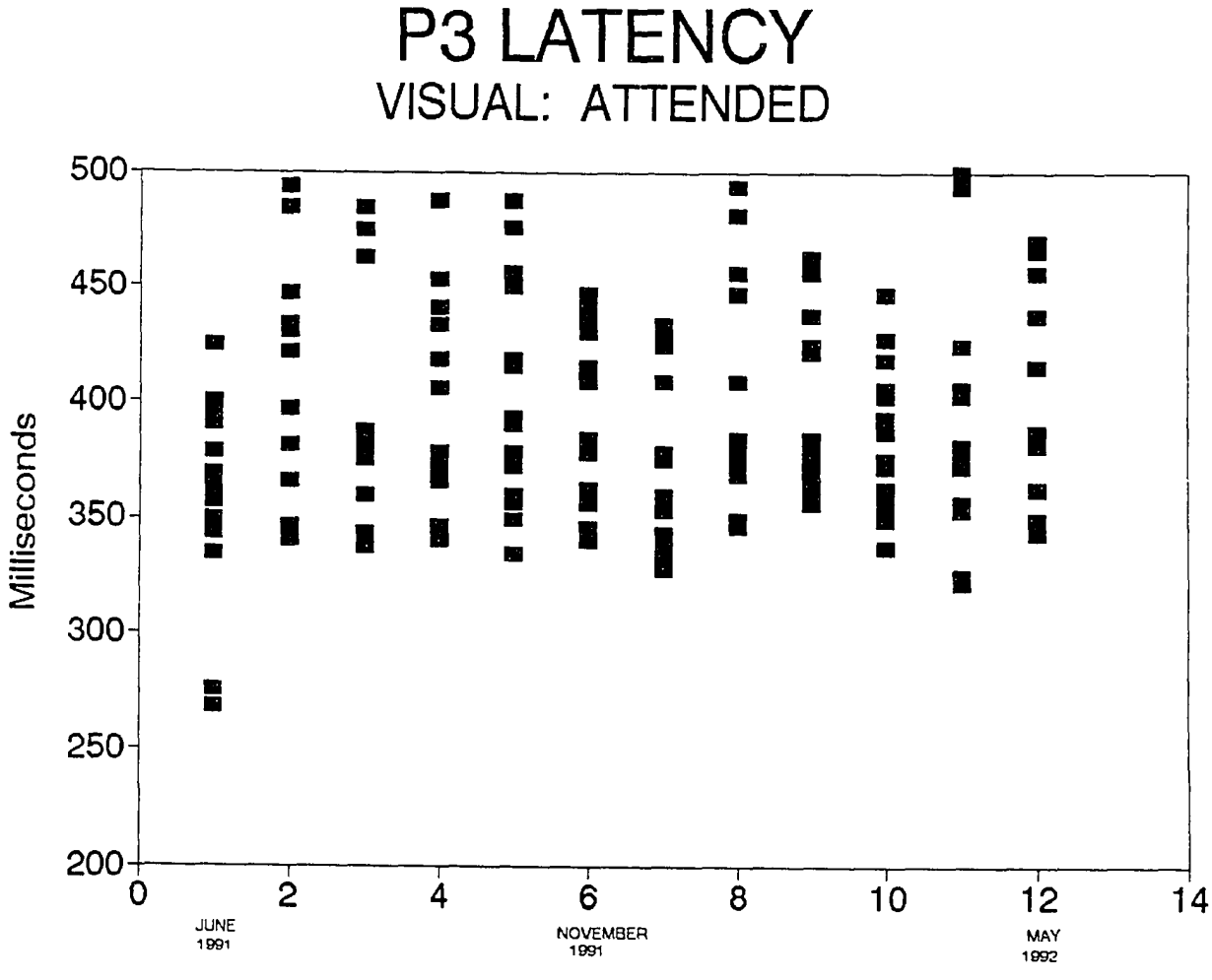


Table 7. Description of attended P3 amplitude recorded over 12 consecutive months.

ATTENDED P3 AMPLITUDE: microvolts
n=8

| | | AUDITORY | | VISUAL | |
|---|---|---|---|---|---|
| | | left | right | left | right |
| MONTH-1 | min | 4.06 | 4.37 | 5.31 | 4.68 |
| June'91 | max | 26.87 | 26.87 | 26.87 | 20.00 |
| | mean | 11.44 | 11.05 | 11.87 | 10.62 |
| | std dev | 6.91 | 7.36 | 7.87 | 5.19 |
| MONTH-2 | min | 5.00 | 2.50 | 10.62 | 10.00 |
| July'91 | max | 32.50 | 25.00 | 22.81 | 25.31 |
| | mean | 14.17 | 12.21 | 16.44 | 15.57 |
| | std dev | 10.63 | 8.65 | 4.92 | 4.45 |
| MONTH-3 | min | 3.12 | 3.43 | 5.62 | 4.62 |
| Aug.'91 | max | 19.37 | 20.62 | 25.93 | 23.75 |
| | mean | 10.15 | 11.05 | 14.68 | 14.63 |
| | std dev | 6.19 | 6.99 | 6.48 | 6.25 |
| MONTH-4 | min | 2.81 | 4.06 | 10.00 | 9.68 |
| Sept.'91 | max | 19.36 | 21.25 | 22.81 | 22.18 |
| | mean | 11.36 | 11.55 | 15.50 | 16.08 |
| | std dev | 6.70 | 6.39 | 5.54 | 4.74 |
| MONTH-5 | min | 4.06 | 1.87 | 6.56 | 7.50 |
| Oct.'91 | max | 18.43 | 19.37 | 26.87 | 22.81 |
| | mean | 11.51 | 12.14 | 14.41 | 14.68 |
| | std dev | 5.00 | 5.76 | 7.46 | 5.57 |
| MONTH-6 | min | 4.68 | 5.62 | 9.37 | 7.81 |
| Nov.'91 | max | 17.50 | 19.06 | 25.93 | 24.06 |
| | mean | 9.09 | 10.56 | 16.55 | 16.44 |
| | std dev | 5.23 | 4.94 | 6.82 | 6.14 |
| MONTH-7 | min | 4.06 | 2.81 | 5.93 | 7.81 |
| Dec.'91 | max | 19.68 | 18.75 | 25.62 | 23.75 |
| | mean | 11.16 | 9.95 | 16.84 | 15.85 |
| | std dev | 5.60 | 5.55 | 7.39 | 6.01 |
| MONTH-8 | min | 2.81 | 2.50 | 9.68 | 8.62 |
| Jan.'92 | max | 15.31 | 18.75 | 21.56 | 21.87 |
| | mean | 9.87 | 10.25 | 13.43 | 14.09 |
| | std dev | 4.78 | 5.41 | 4.51 | 5.38 |
| MONTH-9 | min | 2.18 | 5.00 | 10.00 | 7.81 |
| Feb.'92 | max | 15.03 | 13.12 | 18.43 | 20.63 |
| | mean | 8.59 | 8.92 | 14.37 | 14.33 |
| | std dev | 3.97 | 2.63 | 3.45 | 5.41 |
| MONTH-10 | min | 5.62 | 6.25 | 6.56 | 7.18 |
| March'92 | max | 12.18 | 11.87 | 24.06 | 23.43 |
| | mean | 8.43 | 8.94 | 12.96 | 12.65 |
| | std dev | 2.16 | 2.22 | 5.72 | 5.45 |
| MONTH-11 | min | 2.81 | 2.18 | 7.18 | 8.12 |
| April'92 | max | 14.37 | 15.31 | 18.75 | 18.75 |
| | mean | 8.86 | 9.10 | 15.11 | 13.35 |
| | std dev | 3.78 | 4.89 | 3.78 | 3.62 |
| MONTH-12 | min | 5.31 | 5.00 | 9.84 | 13.12 |
| May'92 | max | 10.31 | 11.25 | 25.31 | 25.31 |
| | mean | 7.86 | 8.03 | 16.46 | 16.59 |
| | std dev | 1.90 | 2.02 | 4.62 | 4.28 |

Table 8. Description of attended P3 latency recorded over 12 consecutive months.

ATTENDED P3 LATENCY: milliseconds
n=8

| | | AUDITORY | | VISUAL | |
|---|---|---|---|---|---|
| | | left | right | left | right |
| MONTH-1 | min | 287.50 | 290.62 | 275.00 | 268.25 |
| June'91 | max | 346.87 | 350.00 | 425.00 | 425.00 |
| | mean | 316.41 | 321.87 | 365.56 | 365.17 |
| | std dev | 24.13 | 23.14 | 44.31 | 48.39 |
| MONTH-2 | min | 293.75 | 303.12 | 340.62 | 346.87 |
| July'91 | max | 421.87 | 421.87 | 484.37 | 493.75 |
| | mean | 331.63 | 337.88 | 408.98 | 410.54 |
| | std dev | 43.51 | 41.40 | 46.90 | 46.94 |
| MONTH-3 | min | 300.00 | 296.87 | 340.62 | 337.50 |
| Aug.'91 | max | 371.87 | 371.87 | 485.00 | 484.37 |
| | mean | 332.42 | 333.20 | 387.49 | 389.84 |
| | std dev | 24.02 | 25.65 | 53.61 | 56.01 |
| MONTH-4 | min | 265.62 | 281.25 | 346.87 | 340.62 |
| Sept.'91 | max | 353.12 | 363.12 | 487.50 | 487.50 |
| | mean | 318.25 | 326.63 | 402.34 | 406.24 |
| | std dev | 27.62 | 27.66 | 45.95 | 48.78 |
| MONTH-5 | min | 246.87 | 246.87 | 350.00 | 334.37 |
| Oct.'91 | max | 381.25 | 384.37 | 487.50 | 476.00 |
| | mean | 307.03 | 312.49 | 400.38 | 398.10 |
| | std dev | 43.39 | 45.01 | 48.22 | 48.44 |
| MONTH-6 | min | 296.87 | 296.87 | 345.78 | 340.62 |
| Nov.'91 | max | 381.25 | 378.12 | 345.78 | 446.87 |
| | mean | 330.85 | 323.04 | 408.34 | 398.82 |
| | std dev | 27.47 | 25.05 | 40.04 | 38.38 |
| MONTH-7 | min | 278.12 | 281.25 | 334.37 | 328.12 |
| Dec.'91 | max | 371.87 | 371.87 | 521.87 | 509.37 |
| | mean | 321.01 | 320.70 | 389.44 | 392.57 |
| | std dev | 31.05 | 30.66 | 64.47 | 59.64 |
| MONTH-8 | min | 256.27 | 259.37 | 346.87 | 350.00 |
| Jan.'92 | max | 443.75 | 425.00 | 481.25 | 493.75 |
| | mean | 323.00 | 323.82 | 399.21 | 414.84 |
| | std dev | 53.73 | 48.23 | 46.64 | 53.15 |
| MONTH-9 | min | 278.12 | 281.25 | 356.25 | 356.25 |
| Feb.'92 | max | 390.62 | 396.87 | 462.50 | 456.25 |
| | mean | 320.31 | 320.71 | 396.87 | 393.74 |
| | std dev | 44.78 | 40.95 | 39.38 | 38.74 |
| MONTH-10 | min | 265.62 | 265.62 | 337.5 | 337.5 |
| March'92 | max | 440.62 | 440.62 | 428.12 | 446.87 |
| | mean | 335.54 | 337.02 | 372.22 | 375.78 |
| | std dev | 53.68 | 51.49 | 33.39 | 37.07 |
| MONTH-11 | min | 259.37 | 262.56 | 321.87 | 325.00 |
| April'92 | max | 353.12 | 356.25 | 500.00 | 493.75 |
| | mean | 317.57 | 317.19 | 396.48 | 392.52 |
| | std dev | 28.63 | 28.67 | 52.67 | 51.26 |
| MONTH-12 | min | 287.50 | 287.50 | 346.87 | 343.75 |
| May'92 | max | 387.50 | 387.50 | 503.12 | 469.87 |
| | mean | 330.85 | 335.93 | 410.15 | 413.81 |
| | std dev | 40.06 | 33.31 | 55.79 | 49.44 |

Table 9. Distribution of raw (untransformed) data. Normality checked via Shapiro-Wilke W-stat.

ATTENDED P3 AMPLITUDE: microvolts
n=8

| | AUDITORY | | VISUAL | |
|---|---|---|---|---|
| | left | right | left | right |
| MONTH-1 June'91 | W = 0.7987 p = 0.024 | W = 0.8475 p = 0.092 | W = 0.8483 p = 0.093 | W = 0.9369 p = 0.585 |
| MONTH-2 July'91 | W = 0.8311 p = 0.062 | W = 0.8820 p = 0.200 | W = 0.8913 p = 0.244 | W = 0.8498 p = 0.097 |
| MONTH-3 Aug.'91 | W = 0.9145 p = 0.392 | W = 0.8924 p = 0.250 | W = 0.9200 p = 0.432 | W = 0.9030 p = 0.312 |
| MONTH-4 Sept.'91 | W = 0.8778 p = 0.182 | W = 0.9416 p = 0.631 | W = 0.8248 p = 0.054 | W = 0.9083 p = 0.347 |
| MONTH-5 Oct.'91 | W = 0.9670 p = 0.871 | W = 0.9545 p = 0.757 | W = 0.8675 p = 0.145 | W = 0.9279 p = 0.502 |
| MONTH-6 Nov.'91 | W = 0.7796 p = 0.018 | W = 0.8829 p = 0.204 | W = 0.8440 p = 0.085 | W = 0.9233 p = 0.461 |
| MONTH-7 Dec.'91 | W = 0.9208 p = 0.442 | W = 0.9253 p = 0.480 | W = 0.9331 p = 0.549 | W = 0.9261 p = 0.486 |
| MONTH-8 Jan.'92 | W = 0.9087 p = 0.350 | W = 0.9433 p = 0.649 | W = 0.8228 p = 0.051 | W = 0.8452 p = 0.087 |
| MONTH-9 Feb.'92 | W = 0.9938 p = 0.998 | W = 0.9822 p = 0.969 | W = 0.8716 p = 0.159 | W = 0.8641 p = 0.134 |
| MONTH-10 March'92 | W = 0.9345 p = 0.562 | W = 0.9132 p = 0.382 | W = 0.9234 p = 0.463 | W = 0.8816 p = 0.198 |
| MONTH-11 April'92 | W = 0.9728 p = 0.916 | W = 0.9390 p = 0.605 | W = 0.8550 p = 0.109 | W = 0.8546 p = 0.108 |
| MONTH-12 May'92 | W = 0.9086 p = 0.349 | W = 0.8975 p = 0.278 | W = 0.9307 p = 0.527 | W = 0.8063 p = 0.034 |

Table 10. Distribution of raw (untransformed) data. Normality checked via Shapiro-Wilke W-stat.

ATTENDED P3 LATENCY: milliseconds
n=8

| | AUDITORY | | VISUAL | |
|---|---|---|---|---|
| | left | right | left | right |
| MONTH-1 | W = 0.8150 | W = 0.9109 | W = 0.9176 | W = 0.9313 |
| June'91 | p = 0.042 | p = 0.910 | p = 0.585 | p = 0.533 |
| MONTH-2 | W = 0.8205 | W = 0.7943 | W = 0.9891 | W = 0.9439 |
| July'91 | p = 0.048 | p = 0.026 | p = 0.991 | p = 0.653 |
| MONTH-3 | W = 0.9330 | W = 0.9532 | W = 0.8184 | W = 0.8502 |
| Aug.'91 | p = 0.549 | p = 0.745 | p = 0.046 | p = 0.097 |
| MONTH-4 | W = 0.9427 | W = 0.9632 | W = 0.9444 | W = 0.9534 |
| Sept.'91 | p = 0.641 | p = 0.839 | p = 0.658 | p = 0.747 |
| MONTH-5 | W = 0.9634 | W = 0.9682 | W = 0.9113 | W = 0.9493 |
| Oct.'91 | p = 0.841 | p = 0.881 | p = 0.368 | p = 0.717 |
| MONTH-6 | W = 0.9587 | W = 0.8452 | W = 0.9042 | W = 0.9463 |
| Nov.'91 | p = 0.798 | p = 0.087 | p = 0.320 | p = 0.677 |
| MONTH-7 | W = 0.9591 | W = 0.9409 | W = 0.8492 | W = 0.9028 |
| Dec.'91 | p = 0.801 | p = 0.624 | p = 0.095 | p = 0.310 |
| MONTH-8 | W = 0.8205 | W = 0.8915 | W = 0.8685 | W = 0.9102 |
| Jan.'92 | p = 0.055 | p = 0.245 | p = 0.148 | p = 0.360 |
| MONTH-9 | W = 0.8542 | W = 0.8719 | W = 0.8812 | W = 0.8497 |
| Feb.'92 | p = 0.107 | p = 0.160 | p = 0.196 | p = 0.096 |
| MONTH-10 | W = 0.9336 | W = 0.9168 | W = 0.9141 | W = 0.9169 |
| March'92 | p = 0.554 | p = 0.409 | p = 0.388 | p = 0.410 |
| MONTH-11 | W = 0.9239 | W = 0.9648 | W = 0.9470 | W = 0.9425 |
| April'92 | p = 0.467 | p = 0.853 | p = 0.684 | p = 0.639 |
| MONTH-12 | W = 0.8586 | W = 0.9330 | W = 0.9380 | W = 0.8968 |
| May'92 | p = 0.118 | p = 0.548 | p = 0.595 | p = 0.274 |

test was performed at alpha = 0.05, we would expect five out of 100 cells to be nonnormal simply by chance. Since six of 96 cells is not significantly different from five of 100 cells, it was concluded that the data distribution was satisfactorily normal and no data transformations were required.

Bbivariate plots (P3 / N4) (S. Emery, personal communication, February, 1993) of the attended waveform for both auditory and visual amplitudes are depicted in Figures 37 and 38. The appearance of an N1 is dependent upon the detection of supra-threshold stimuli, however, the N1 is not correlated with qualitative aspects of perception (Rockstroh, et al., 1989). The P3, on the other hand, does vary with qualitative aspects of perception (Karrer, et al., 1984; Rockstroh, et al., 1989). Bivariate plotting of the two amplitudes, as shown in Figures 37 and 38, serves as a check for systematic recording errors, or "noise". If a linear relationship is observed (large N1 amplitudes associated with large P3 amplitudes), this would suggest the presence of a process common to both components: for example, recording artifact from electrical interference or a technical artifact such as thermal drift of the preamplifier. As can be seen in Figures 37 and 38, such a linear relationship is not apparent.

Analysis. The experimental design consisted of two balanced fixed effects analyses of variance (amplitude, latency) for

Figure 37. "Noise" diagnostic plot of auditory attended P3 amplitude vs auditory attended N1 amplitude.

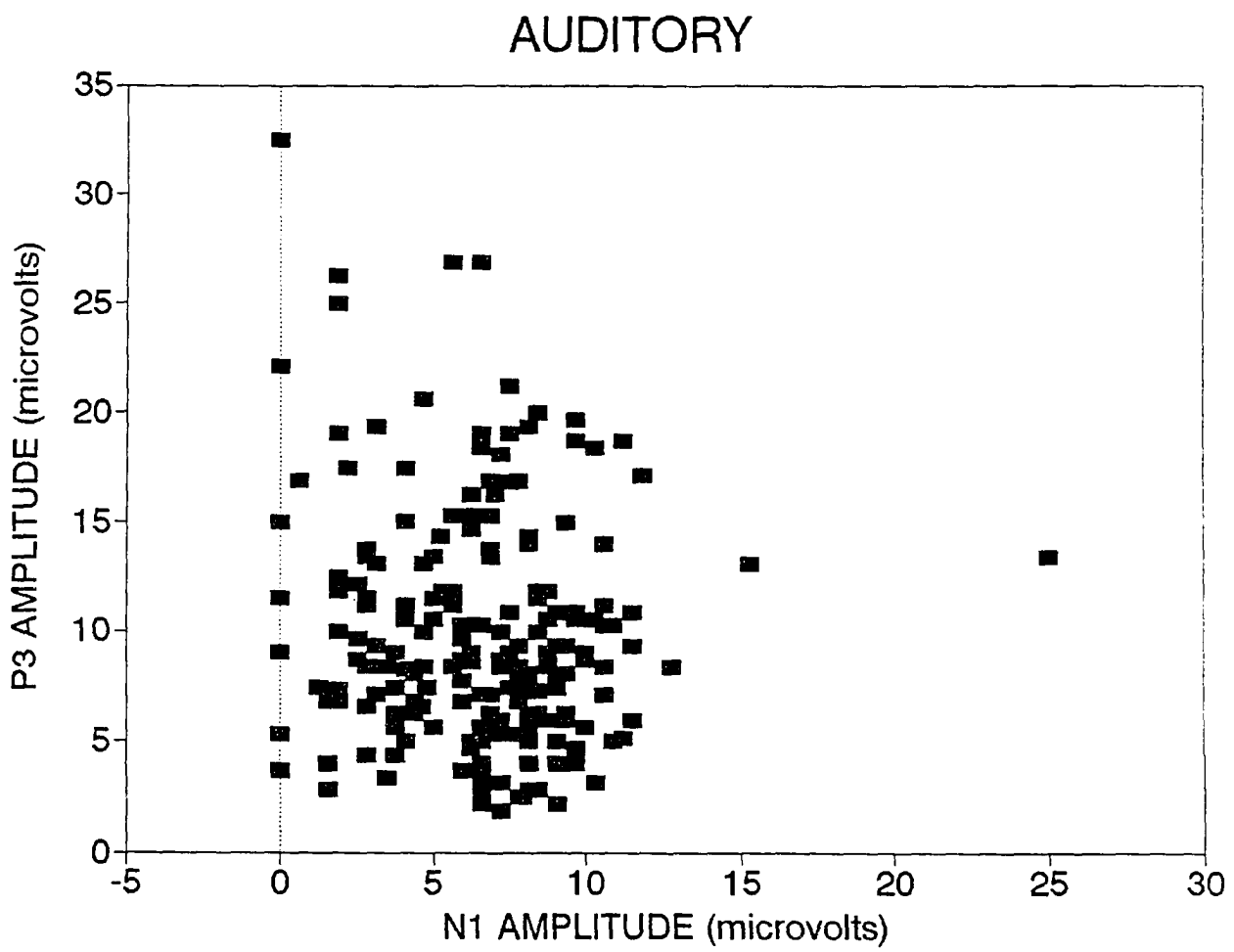
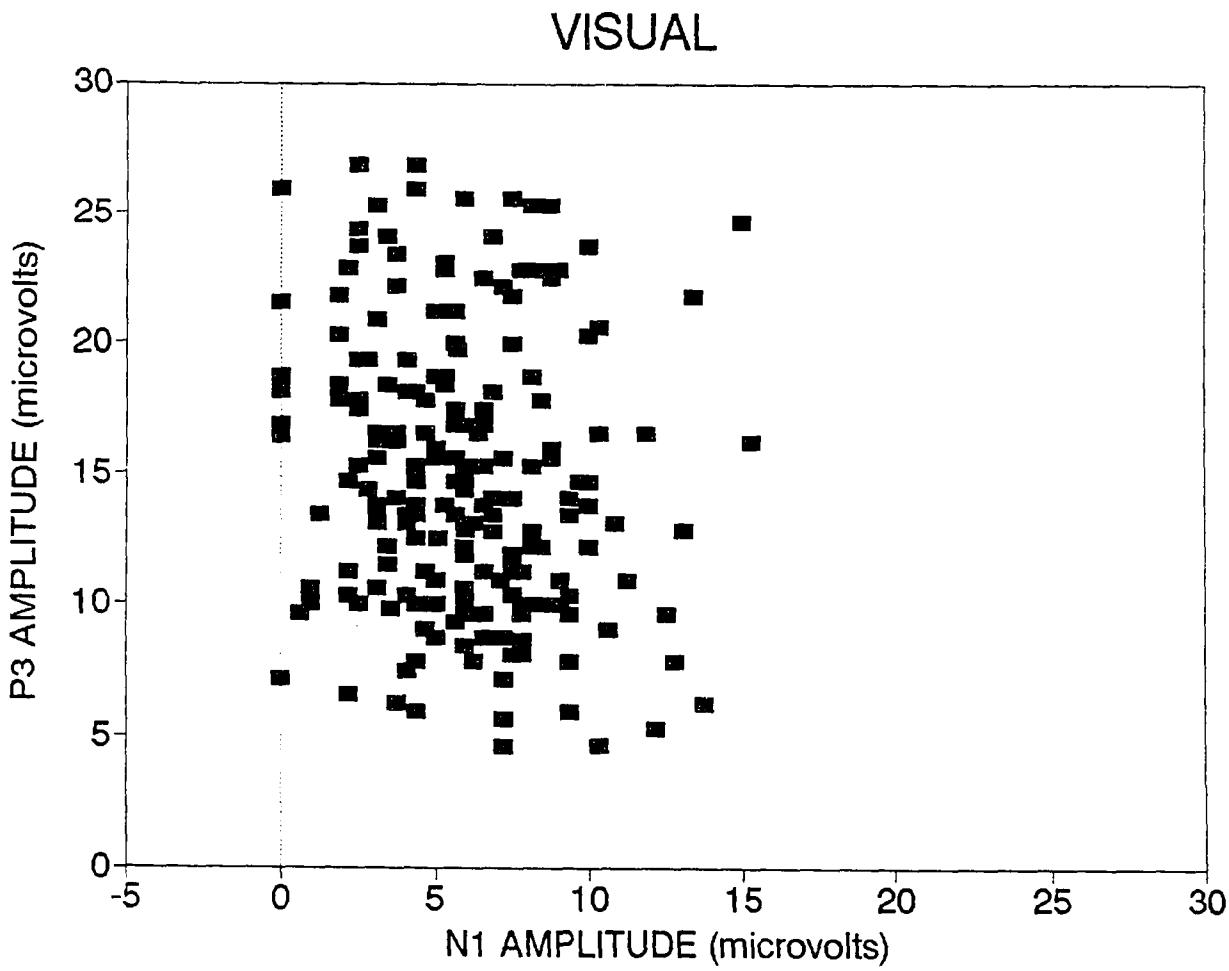


Figure 38. "Noise" diagnostic plot of visual attended P3 amplitude vs visual attended N1 amplitude.



ordered (12 consecutive months) repeated measures (same subjects every month). The conservative technique of the general linear model analysis of variance for repeated measures, GLM-ANOVA-rm, (Dixon, 1990; Neter, Wasserman, & Kutner, 1985; SAS/STAT 1989)was used to test for a month effect on amplitude, an independently, for a month effect on latency. Two independent (amplitude and latency) analyses were necessary because of the technological limitations of the VAX/VMS mainframe computer and software.

The test statistic used in the GLM-ANOVA-rm is Wilks' Lambda which tests the equality of group means in the function defined by the model statement. Data from the two sides of each subject's head were treated as subsamples, rather than replicates, which increases the specificity of the general linear model (Anderson, & McLean, 1974). It is necessary to include the restriction "no univariate" since the 12 months were considered as 12 levels of a single factor, time (SAS/STAT, 1989). The design used the SAS language model statement:

```
Month_1 - Month_12 = constant + mode + hemisphere/nouni;
      repeated months;
      pairwise means / Tukey HSD alpha = 0.05.
```

==========

I. Ho: No month effect.
Ha: Month effect detected.

AMPLITUDE:
Wilks' Lambda: F (11,19) = 2.7804 Pr > F = 0.0244

LATENCY:
Wilks' Lambda: F (11,19) = 3.0506 Pr > F = 0.0160

==========

Conclusion. There is a significant effect of the level (1 - 12) of time (month) in the ERP data. The monthly mean values of the attended P3 ERP characteristics of amplitude and latency, measured on the same subjects living at high latitude, for 12 consecutive months, are significantly different from month to month.

==========

II. Ho: No month * sensory mode interraction noted.
Ha: An interraction is detected.

AMPLITUDE:
Wilks' Lambda: F (11,19) = 5.9028 Pr > F = 0.0004

LATENCY:
Wilks' Lambda: F (11,19) = 3.6168 Pr > F = 0.0069

==========

Conclusion. There is a highly significant interraction between the level of time (month) and the ERP sensory modality recorded.

Pairwise Comparisons. As specified in the model statement, each GLM-ANOVA-rm was followed by Tukey's Honestly Significant Difference, HSD, pairwise comparisons of the means, with experiment-wise error controlled at 0.05. No particular month was detected as significantly different from any other month. However, it is necessary to point out that the number of pairwise comparisons required (66) reduces each comparison's alpha level to 0.0008. No monthly mean amplitdue, or latency, or modality interraction, was detectable at that level of significance.

Conclusions. The event-related responses recorded from normal humans, using two sensory modalities, varied significantly over the course of 12 months at high latitude. Pairwise comparisons did not identify any one month as particularly different from any other month. Further evaluation is necessary to ascertain whether this monthly variability might be reasonable attributed to fluctuation in environmental variables such as photoperiod (experiment seven) or geomagnetic field flux (experiment eight) wich vary considerably at this ERP recording location.

The highly significant month interraction with sensory modality may be an amplification of the inherent differences in the two forms of ERP testing (see experiment four, part three). Further evaluation is necessary to ascertain whether the interraction can be reasonably attributed to a modality-specific response to variability in the environmental factors (see experiments seven and eight).

# EXPERIMENT SIX

## Principal Components Analysis of the Independent Variables in the Longitudinal Study of Normal Humans at High Latitude.

Bush, A. M.

## EXPERIMENT SIX

### Principal Components Analysis of the Independent Variables in the Longitudinal Study of Normal Humans at High Latitude.

Having observed a month effect in the event-related potential data collected from the longitudinal study group, principal components analysis, PCA, was used to evaluate the relative extent to which the independent variables contributed to the variability observed in the ERP data.

The PCA method of factor analysis is a multivariate technique for examining relationships among several quantitative variables, and is a useful tool to obtain a parsimonious description for a set of continuous, intercorrelated variables. The general objectives of PCA factor analysis are:

-1) to study the intercorrelations of a large number of variables by clustering them into common factors, such that variables within each factor are highly correlated.

-2) to interpret each factor according to the variables with high factor loadings belonging to it.

-3) to summarize many variables by a few factor or summary scores, with the assumption that the number of factors will be appreciably less than the original number of variables (Dixon, 1990; SAS/STAT, 1989).

The result of PCA factor analysis is to reduce the number of variables to be used in regression, clustering, exploring polynomial relationships, and so forth. Thus, PCA has a variety of useful properties and those particularly useful in the present investigation include:

"-the first principal component has the largest variance of any unit-length linear combination of the observed variables.

-the scores on the first j principal components have the highest possible generalized variance of any set of unit-length linear combination of the original variables.

-the first j principal components are the best linear predictors of the original variables among all possible sets of j variables. This is equivalent to minimizing the determinant of a matrix.

-the j-dimensional linear subspace spanned by the first j principal components gives the best possible fit to the data points as measured by the sum of squared perpendicular distances from each data point to the subspace" (SAS/STAT, 1989, pg. 1241).

It is important to emphasize that PCA factor analysis is not used for hypothesis testing. The PCA analysis was performed with BMDP (Dixon, 1990) subroutine 4M, running on VAX/VMS mainframe computer.

Results. A descriptive summary of the independent variables measured over 12 consecutive months at high latitude, as well as the matrices of correlation to, and covariance with, the ERP data are shown in Table 11.

The initial condition was 49.24, which describes the largest eigenvalue of the correlation matrix divided by the smallest. Numbers close to one indicate little linear dependence and/or many factors. Note that the term "factor", as used here, does not refer to one of the independent variables. The initial condition observed is quite large, which indicates greater linear dependence and fewer factors.

Carmine's Theta was 0.7611 (range -1.0 to +1.0), which describes the internal consistency of the data. Values close to 1.0 support internal consistency, while those close to zero do not.

The communality of the ERP data with the PCA Factors was observed to be:

ERP Data : PCA Factor Communality

| | |
|---|---|
| Auditory Amplitude | = 0.6549 |
| Auditory Latency | = 0.7010 |
| Visual Amplitude | = 0.6780 |
| Visual Latency | = 0.5873 |

The communality of a variable shows how much of each variable's total variance is accounted for by the PCA factors (Dixon, 1990). In the 12-month data set, over 50%

Table 11. Descriptive summary of the independent variables and their correlation and covariance with the ERP data.

General Description: Independent Variables over 12 months

| Variable | Mean | Std.Dev. | C.V.* | Range |
|---|---|---|---|---|
| age | 25.41 | 12.50 | 0.4921 | (9.75-46.58) |
| cranial capacity | 1416.52 | 218.06 | 0.1539 | (1092-1836) |
| sleep epoch lgth. | 7.99 | 1.63 | 0.2046 | (00.25-12.00) |
| sleepiness scale | 7.07 | 1.46 | 0.2074 | (3.0-9.0) |
| photoperiod | 12.31 | 5.81 | 0.4724 | (3.31-21.98) |
| TMF-room | 496.19 | 15.18 | 0.0306 | (426.62-534.86) |
| prior Ak | 26.26 | 20.30 | 0.7732 | (2.00-97.00) |
| sum 24-hr. k | 24.61 | 10.27 | 0.4174 | (5.00-48.00) |
| current 3-hr. k | 2.66 | 1.67 | 0.6290 | (0.00-9.00) |
| prior 3-hr. k | 3.26 | 1.57 | 0.4839 | (0.00-7.00) |

*Coefficient of Variation

The Correlation Matrix

| VARIABLE | AUD.AMP. | AUD.LAT. | VIS.AMP. | VIS.LAT. |
|---|---|---|---|---|
| age | -0.360 | -0.375 | -0.443* | -0.454 |
| cranial capacity | -0.448* | -0.390* | -0.307 | -0.590* |
| sleep epoch lgth. | 0.344 | 0.061 | 0.180 | 0.384 |
| sleepiness scale | -0.087 | -0.045 | -0.181 | -0.154 |
| photoperiod | 0.075 | 0.057 | -0.076 | -0.044 |
| TMF-room | 0.060 | 0.151 | 0.062 | 0.266 |
| current 3-hr. k | 0.056 | 0.199 | -0.153 | -0.091 |
| prior 3-hr. k | 0.137 | 0.178 | -0.066 | -0.064 |
| sum 24-hr. k | 0.246 | 0.036 | -0.170 | 0.105 |
| prior Ak | 0.272 | 0.037 | -0.203 | -0.005 |

* Strongest Linear Relationship

The Covariance Matrix

| VARIABLE | AUD.AMP. | AUD.LAT | VIS.AMP. | VIS.LAT. |
|---|---|---|---|---|
| age | -24.40 | -168.66 | -29.03 | -264.78 |
| cranial capacity | -528.78* | -3058.87* | -350.82* | -5993.95* |
| sleep epoch lgth. | 3.04 | 3.56 | 1.54 | 29.24 |
| sleepiness scale | -0.05 | -2.34 | -1.39 | -10.50 |
| photoperiod | 2.37 | 11.99 | -2.39 | -12.44 |
| TMF-room | 4.91 | 82.16 | 4.92 | 187.95 |
| current 3-hr. k | 0.50 | 11.98 | -1.34 | -7.07 |
| prior 3-hr. k | 1.16 | 10.08 | -8.54 | -4.69 |
| sum 24-hr. k | 13.69 | 13.29 | -9.17 | 50.26 |
| prior Ak | 29.87 | 26.68 | -21.64 | -4.51 |

* Strongest covariants

of each ERP characteristic's total variance is accounted for by the PCA factors.

The first five PCA factors explained 100% of the variance in factor space, and 73.2% of the variance in data space. Total variance is defined as the sum of the positive eigenvalues of the correlation matrix (Dixon, 1990). Fourteen PCA factors explained 100% of the variance in data space, however, contributions beyond the third PCA factor were less than 10%.

The PCA factors were orthogonally rotated (varimax rotation) to minimize the simplicity criterion G. The purpose of this procedure is to make the loading coefficients for each factor large, or small, but not intermediate (Dixon, 1990, pg. 322). By using varimax rotation, the PCA factor scores remain uncorrelated. The rotated factor coefficents were then sorted in descending order of variance explained. In this scheme, PCA factor-1 explains more of the variance than PCA factor-2, and within each PCA factor, items with larger loading coefficients explain more variance than items with smaller loading coefficients. The results are shown in Table 12.

On the basis of the results from the Principal Components method of factor analysis, the independent variables from the longitudinal study can be clustered as shown in Table 12. Scattergraphs which compare the ERP data to those independent variables which clustered into group one are listed in Table 13. Those independent variables

Table 12. Sorted PCA factor loadings of the independent variables and clustering based on factor loading coefficients.

PRINCIPAL COMPONENTS: Factor Loading Coefficients of the Independent Variables

| VARIABLE | Factor-1 | Factor-2 | Factor-3 | Factor-4 | Factor-5 |
|---|---|---|---|---|---|
| age | -0.589 | 0.000 | 0.000 | -0.554 | 0.000 |
| sum 24 k | 0.000 | 0.943 | 0.000 | 0.000 | 0.000 |
| prior 24 k | 0.000 | 0.937 | 0.000 | 0.000 | 0.000 |
| prior 3 k | 0.000 | 0.000 | 0.891 | 0.000 | 0.000 |
| current k | 0.000 | 0.000 | 0.888 | 0.000 | 0.000 |
| cran. cap. | -0.584 | 0.000 | 0.000 | -0.607 | 0.000 |
| TMF-rm. | 0.000 | 0.000 | -0.444 | 0.523 | 0.500 |
| sleep scl. | 0.000 | 0.000 | 0.000 | 0.000 | 0.776 |
| hrs. sleep | 0.552 | 0.000 | 0.000 | 0.000 | 0.590 |
| photoperiod | 0.000 | 0.269 | 0.399 | 0.000 | -0.562 |
| Variance Explained: | 0.2435 | 0.2082 | 0.1161 | 0.0918 | 0.0736 |

Independent Variables Clustered (without replacement) by PCA factor loading coefficients:

GROUP 1:
- age ..... (-0.598, factor-1)
- cranial capacity (-0.584, factor-1)
- sleep length ( 0.552, factor-1)

GROUP 2:
- sum 24-hour k-indices ..... ( 0.943, factor-2)
- prior 24-hour k-index ( 0.937, factor-2)
- photoperiod ( 0.269, factor-2)

GROUP 3:
- prior 3-hour k-index ..... ( 0.891, factor-3)
- current 3-hour k-index ( 0.888, factor-3)
- total magnetic field in room (-0.444, factor-3)

GROUP 4:
- subjective wakefulness ..... (0.776, factor-5)

which clustered into group two, specifically photoperiod and geomagnetic field strength, are investigated separately in experiments seven and eight, however, a time series plot of the ERP characteristics (amplitude and latency, auditory and visual) and environmental variables is presented here in Figure 52.

Table 13. List of plots which follow cluster analysis. Independent variables from the PCA which clustered into group one (Table 12) are plotted against the 12-month ERP data.

| | | |
|---|---|---|
| AGE | Auditory Amplitude | (Figure 39) |
| | Visual Amplitude | (Figure 40) |
| | Auditory Latency | (Figure 41) |
| | Visual Latency | (Figure 42) |
| CRANIAL VOLUME | Auditory Amplitude | (Figure 43) |
| | Visual Amplitude | (Figure 44) |
| | Auditory Latency | (Figure 45) |
| | Visual Latency | (Figure 46) |
| LAST SLEEP LENGTH | Auditory Amplitude | (Figure 47) |
| | Visual Amplitude | (Figure 48) |
| | Auditory Latency | (Figure 49) |
| | Visual Latency | (Figure 50) |
| Sleep Length vs Photoperiod | | (Figure 51) |
| Time Series of ERP Data | | (Figure 52) |

Figure 39. Auditory P3 amplitude plotted by age.

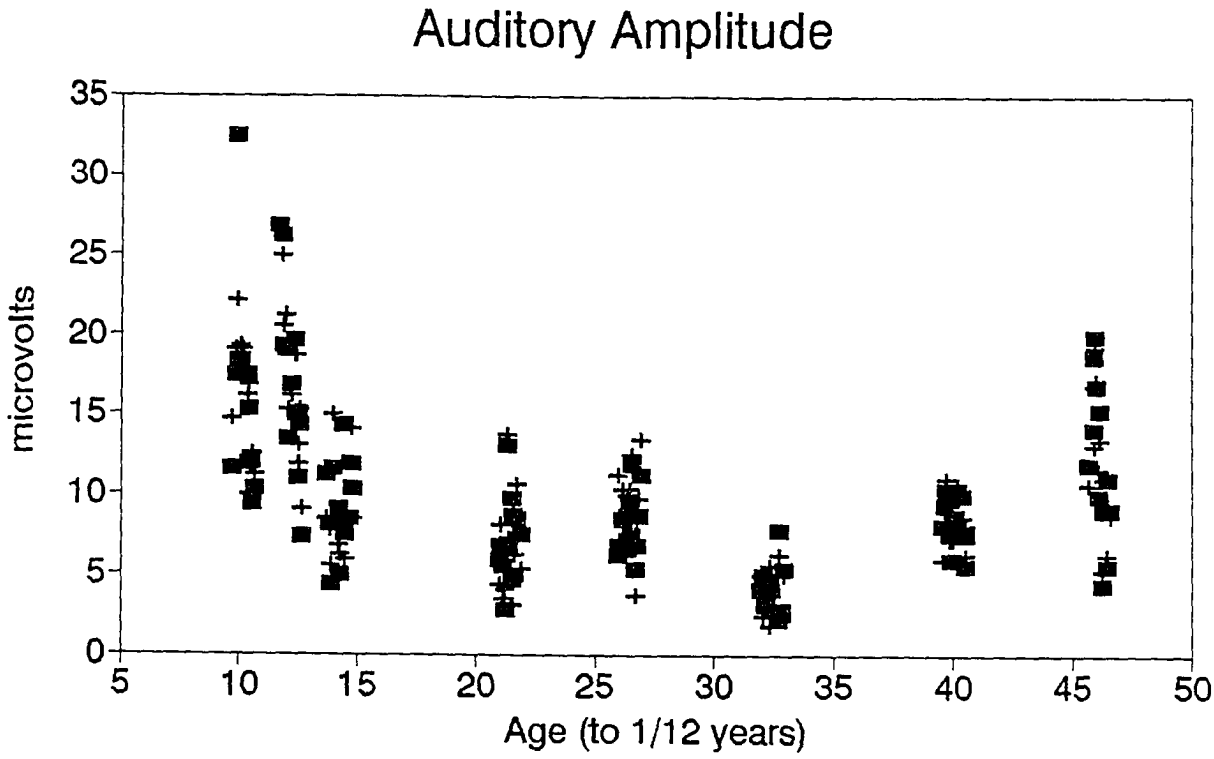


Figure 40. Visual P3 amplitude plotted by age.

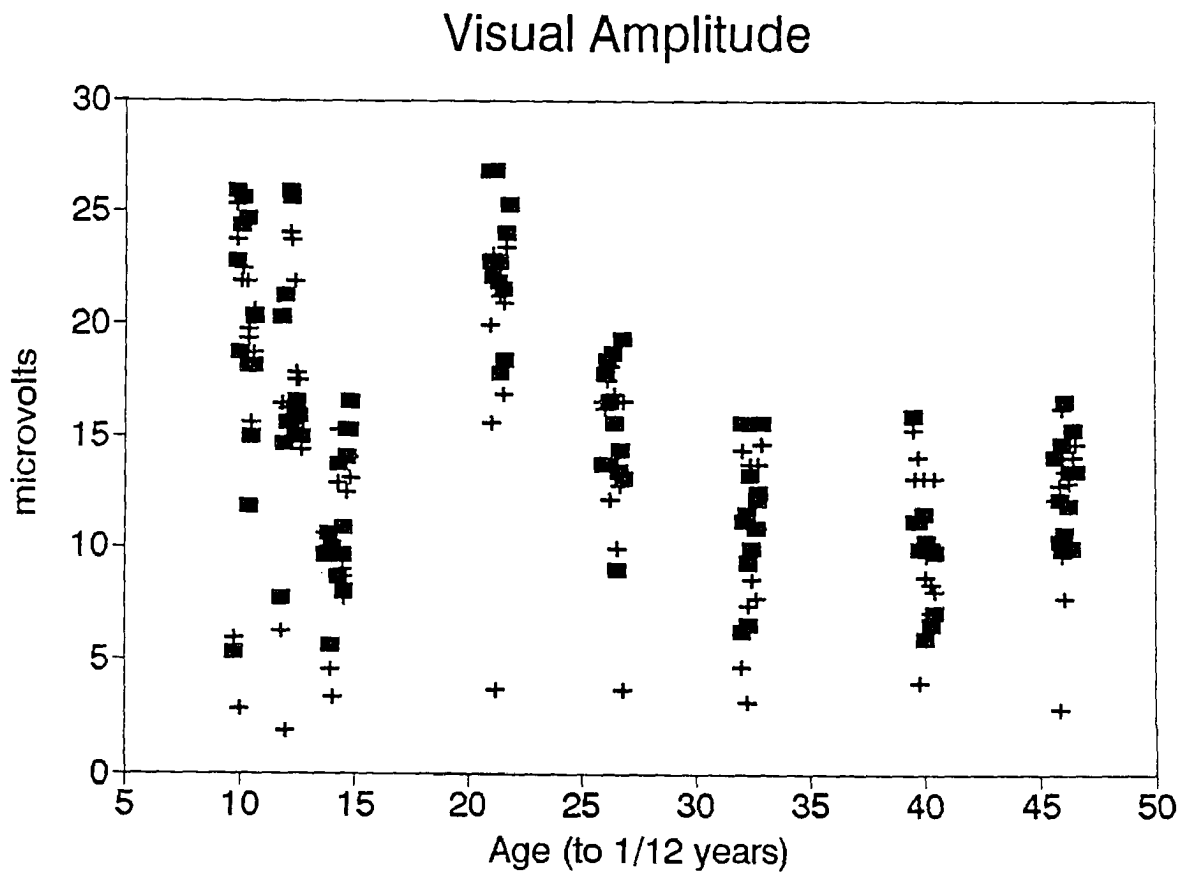


Figure 41. Auditory P3 latency plotted by age.

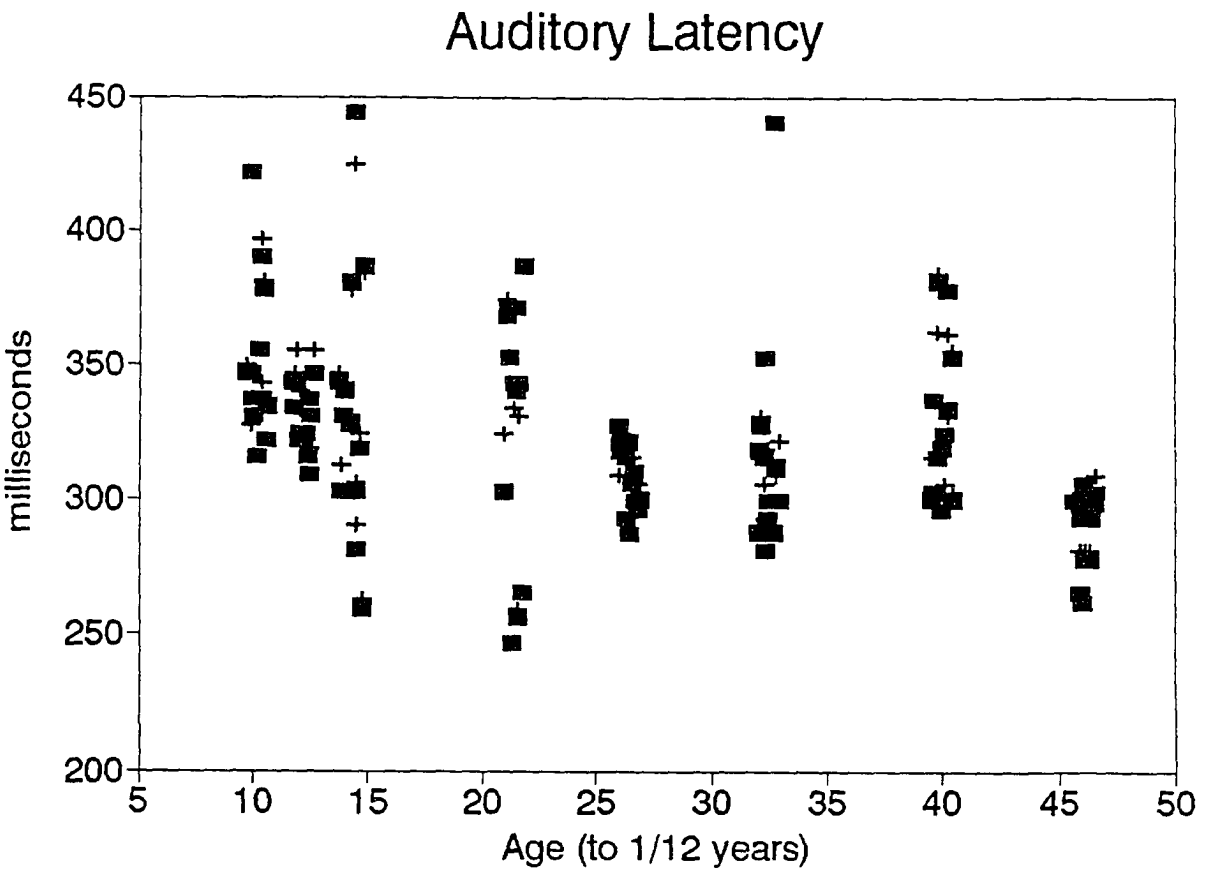


Figure 42. Visual P3 latency plotted by age.

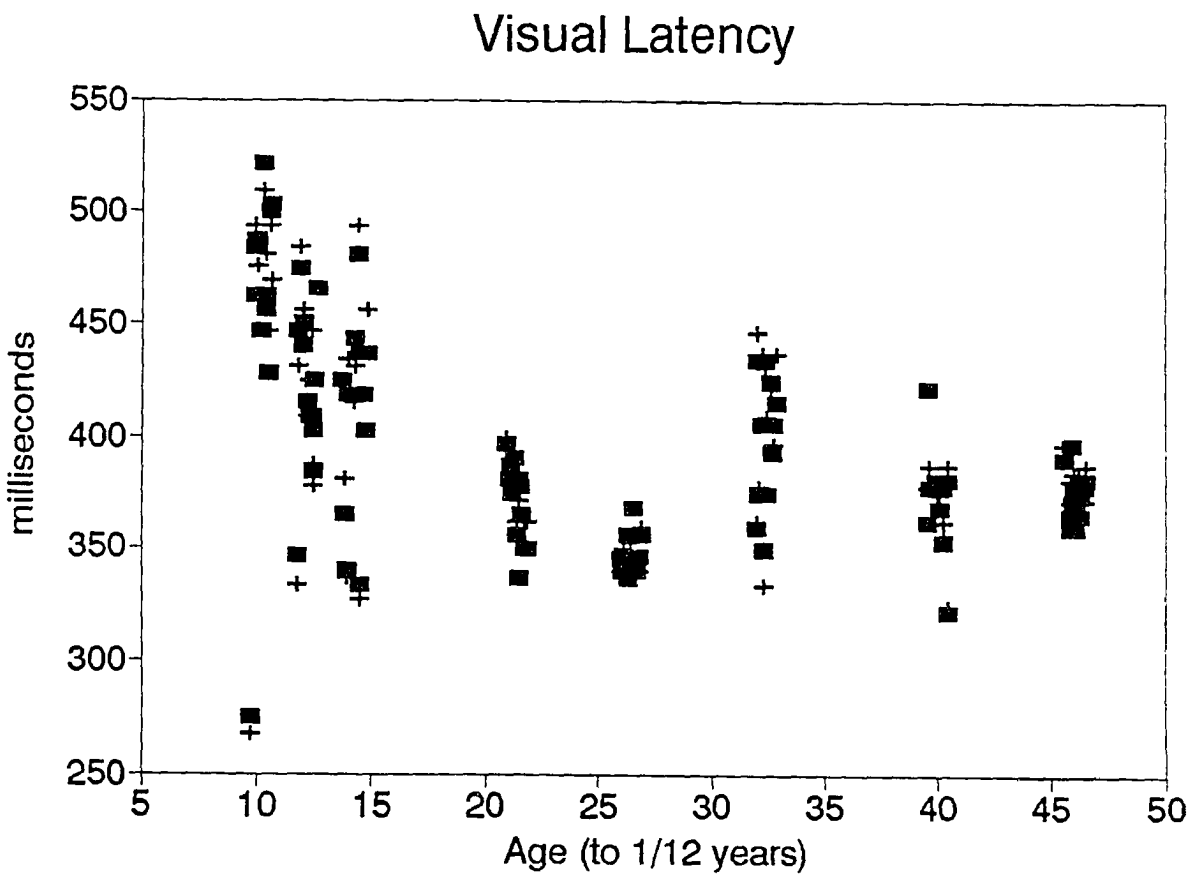


Figure 43. Auditory P3 amplitude plotted by cranial volume.

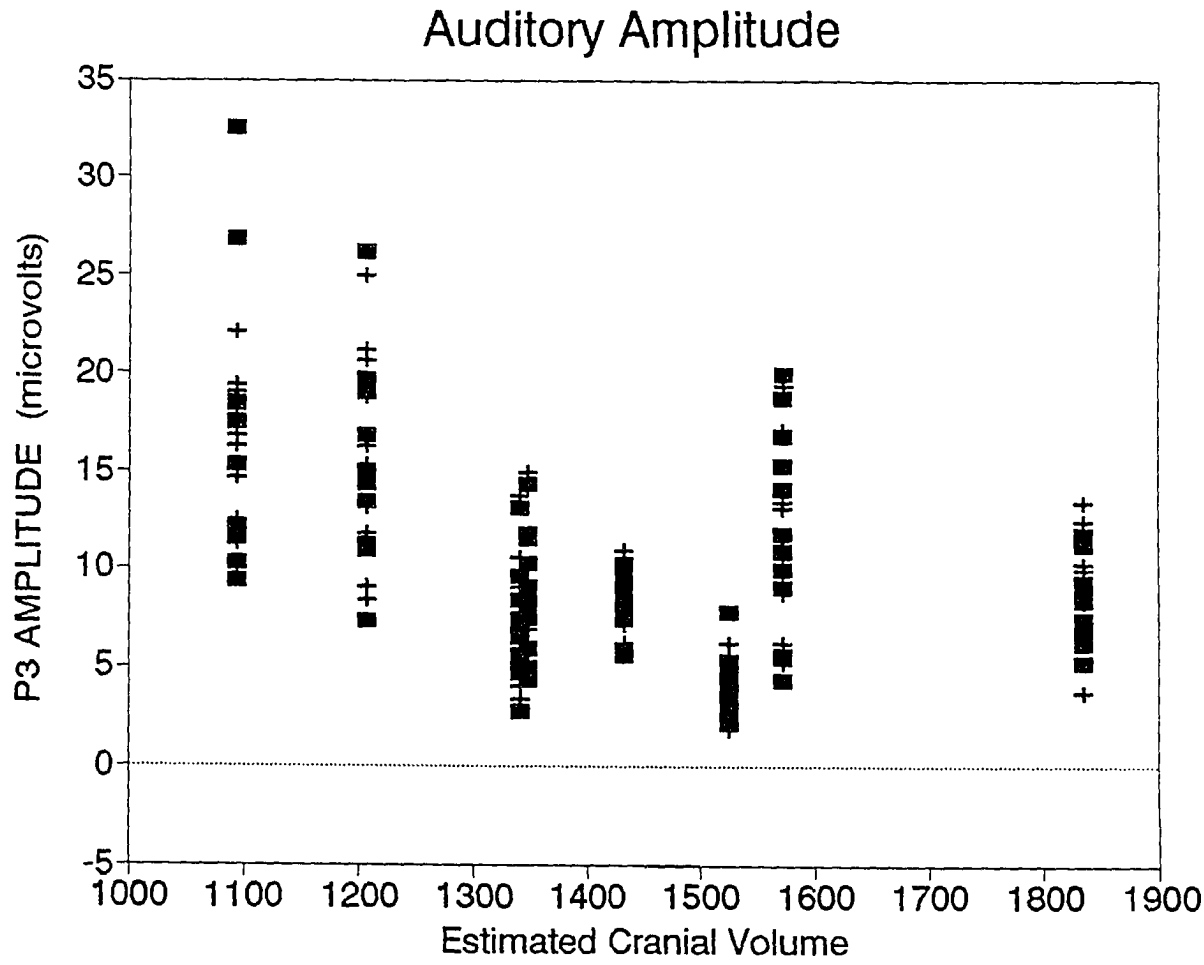


Figure 44. Visual P3 amplitude plotted by cranial volume.

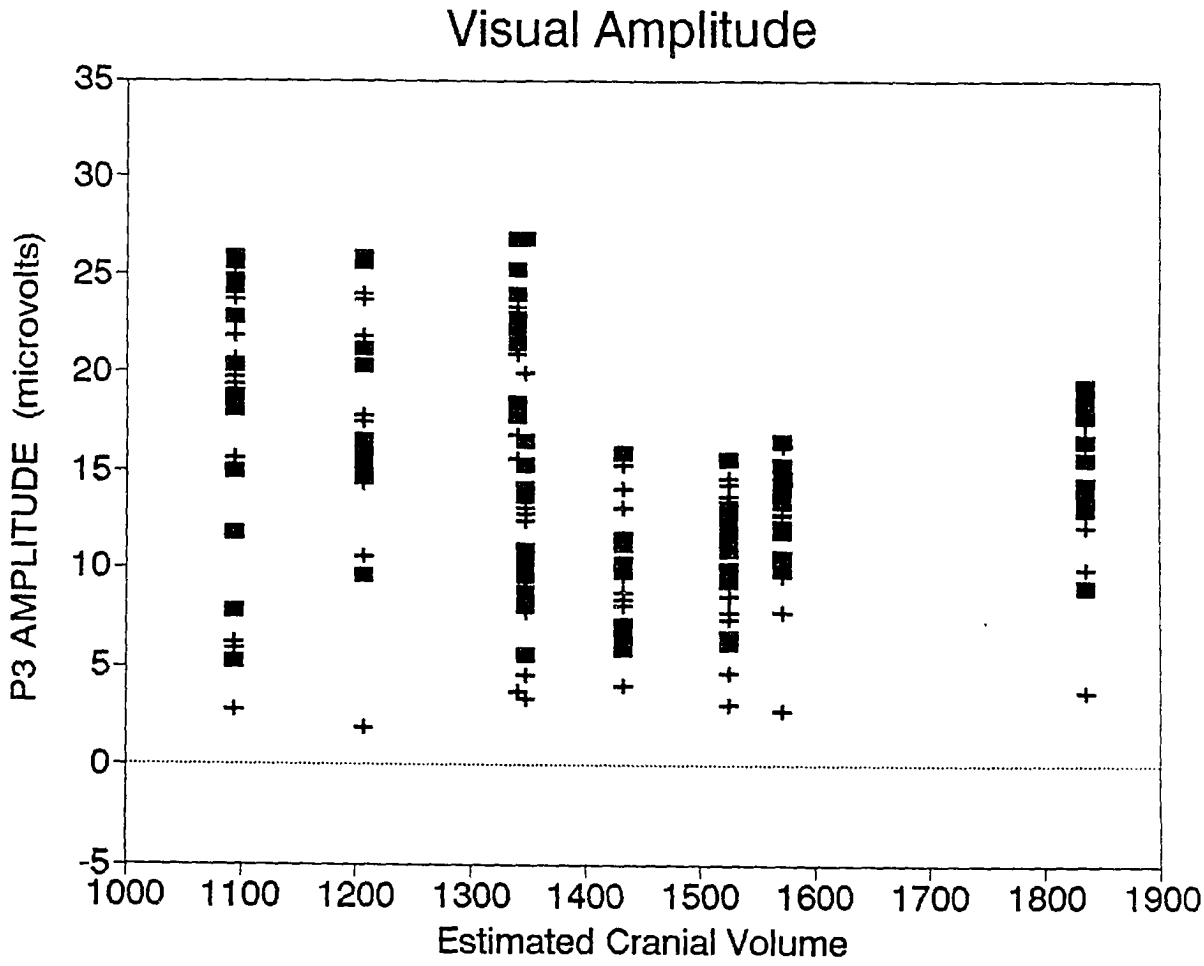


Figure 45. Auditory P3 latency plotted by cranial volume.

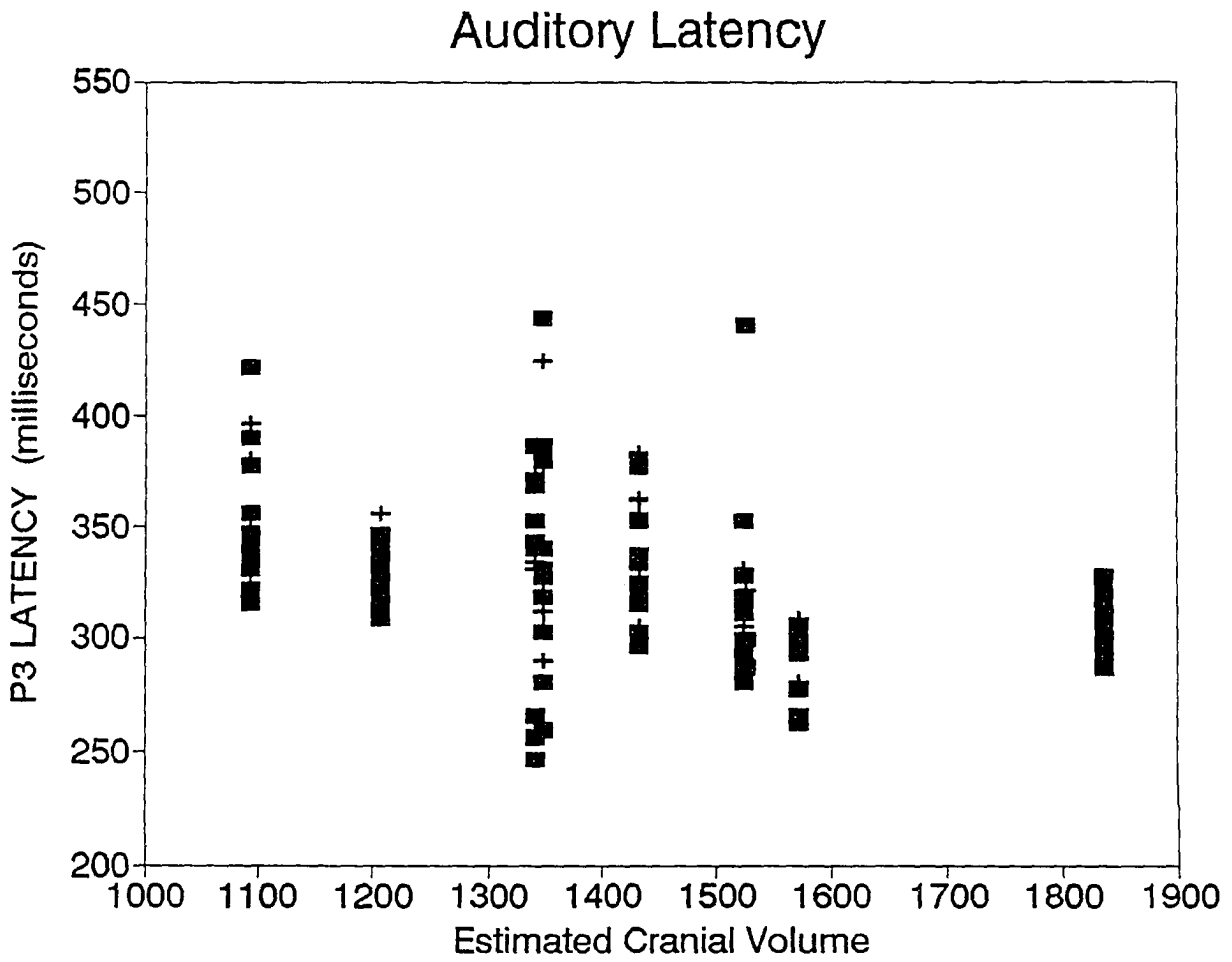


Figure 46. Visual P3 latency plotted by cranial volume.

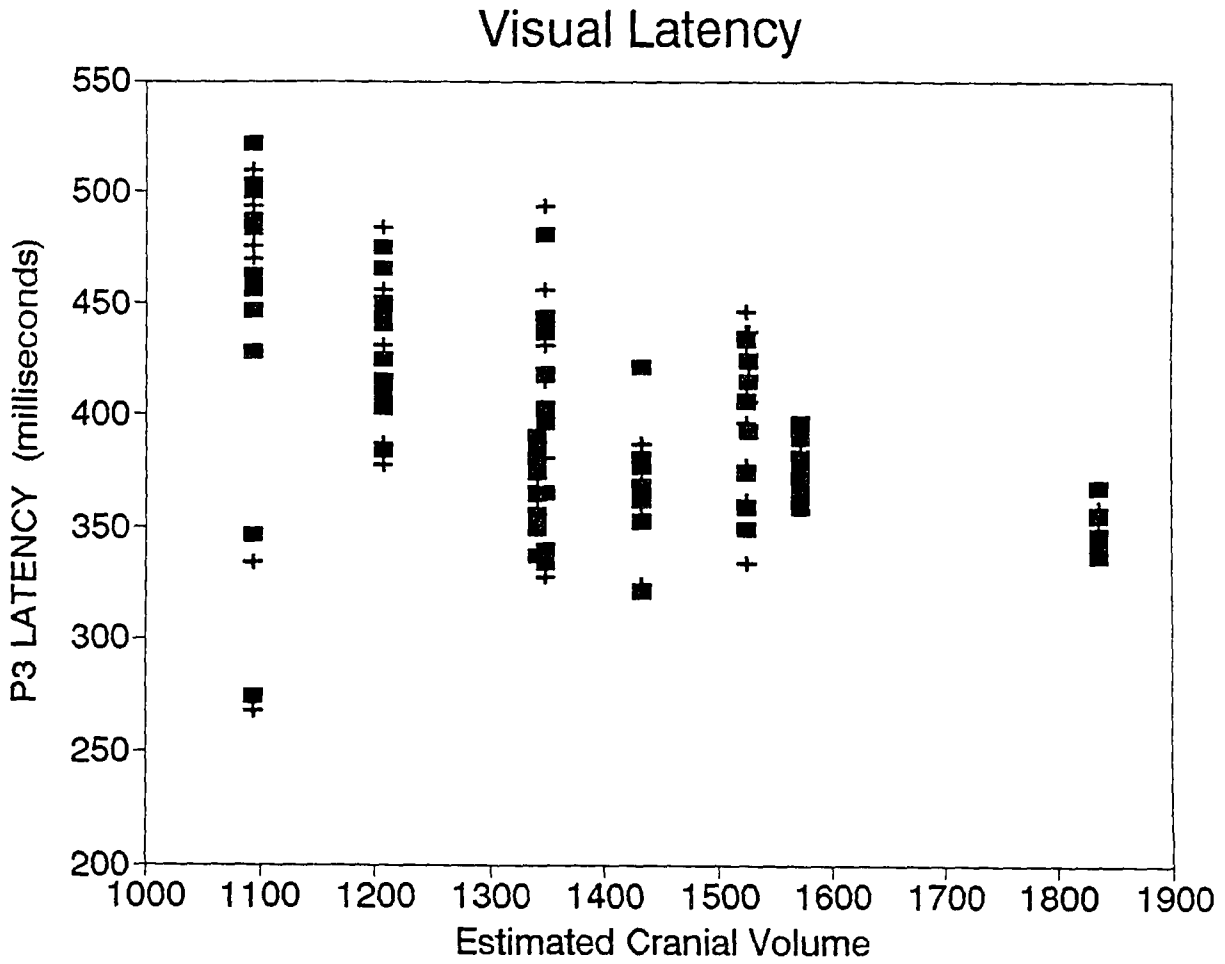


Figure 47. Auditory P3 amplitude plotted by last sleep length.

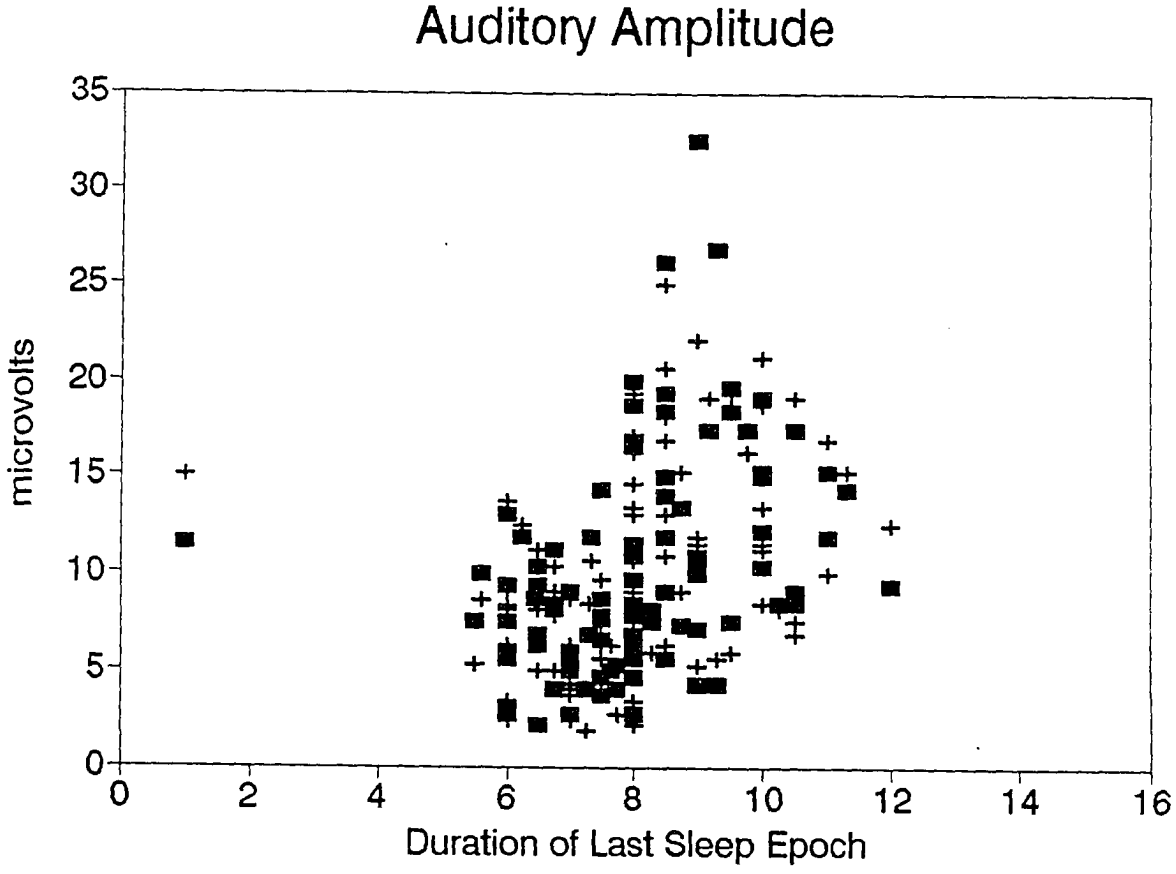


Figure 48. Visual P3 amplitude plotted by last sleep length.

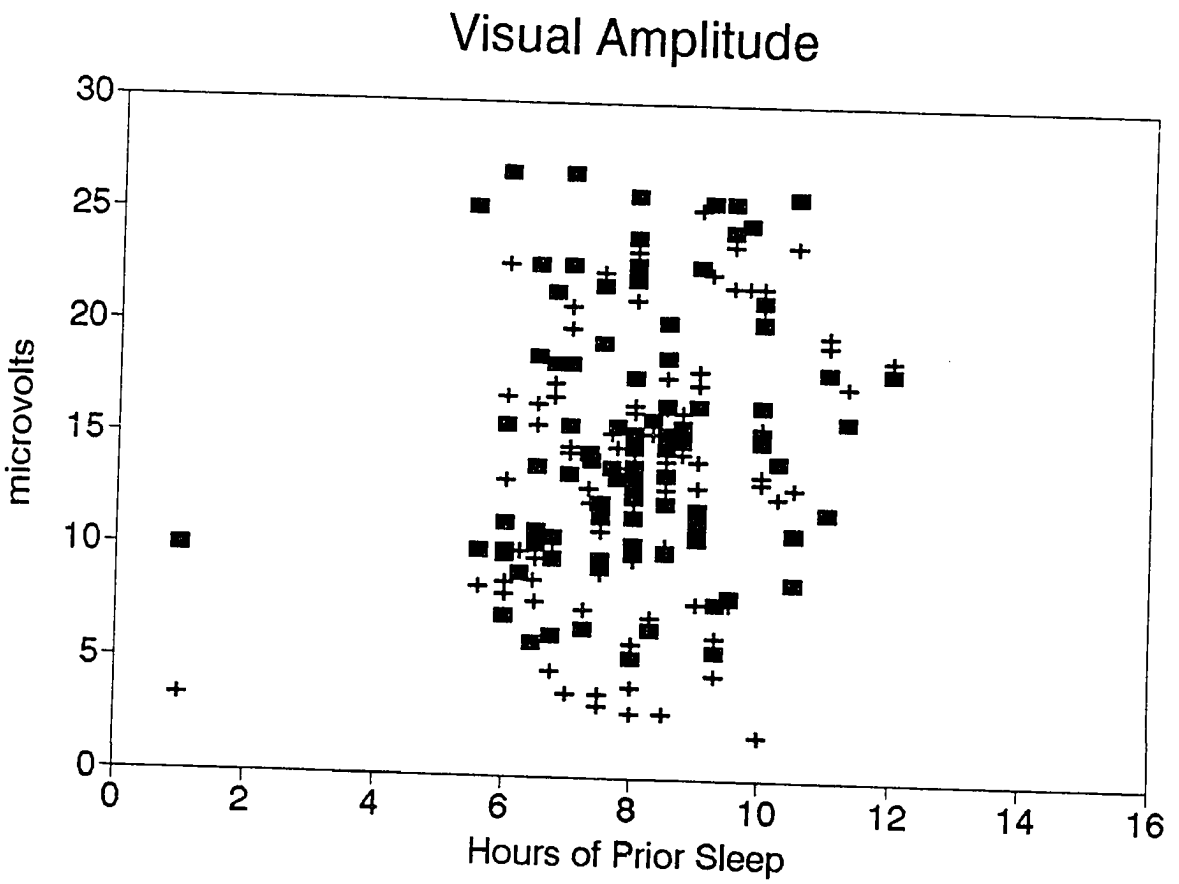


Figure 49. Auditory P3 latency plotted by last sleep length.

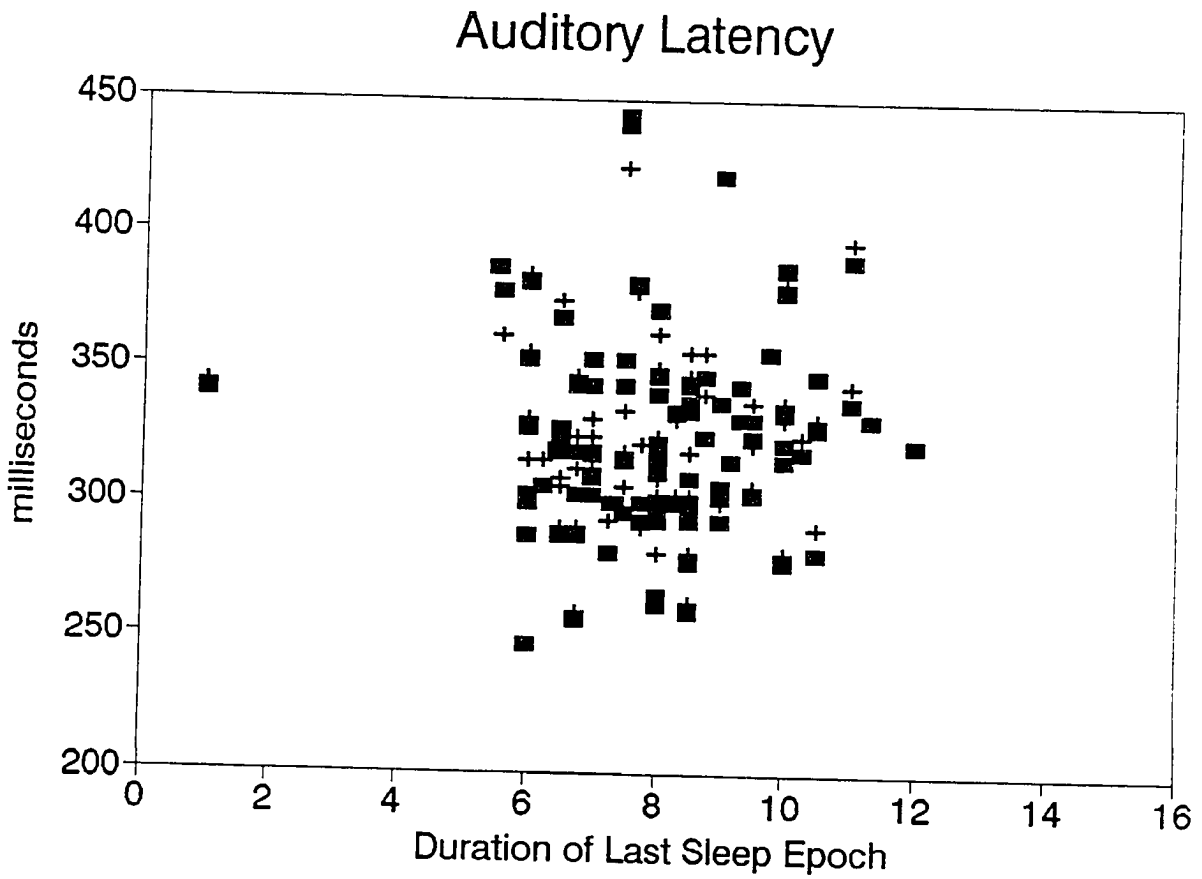


Figure 50. Visual P3 latency plotted by last sleep length.

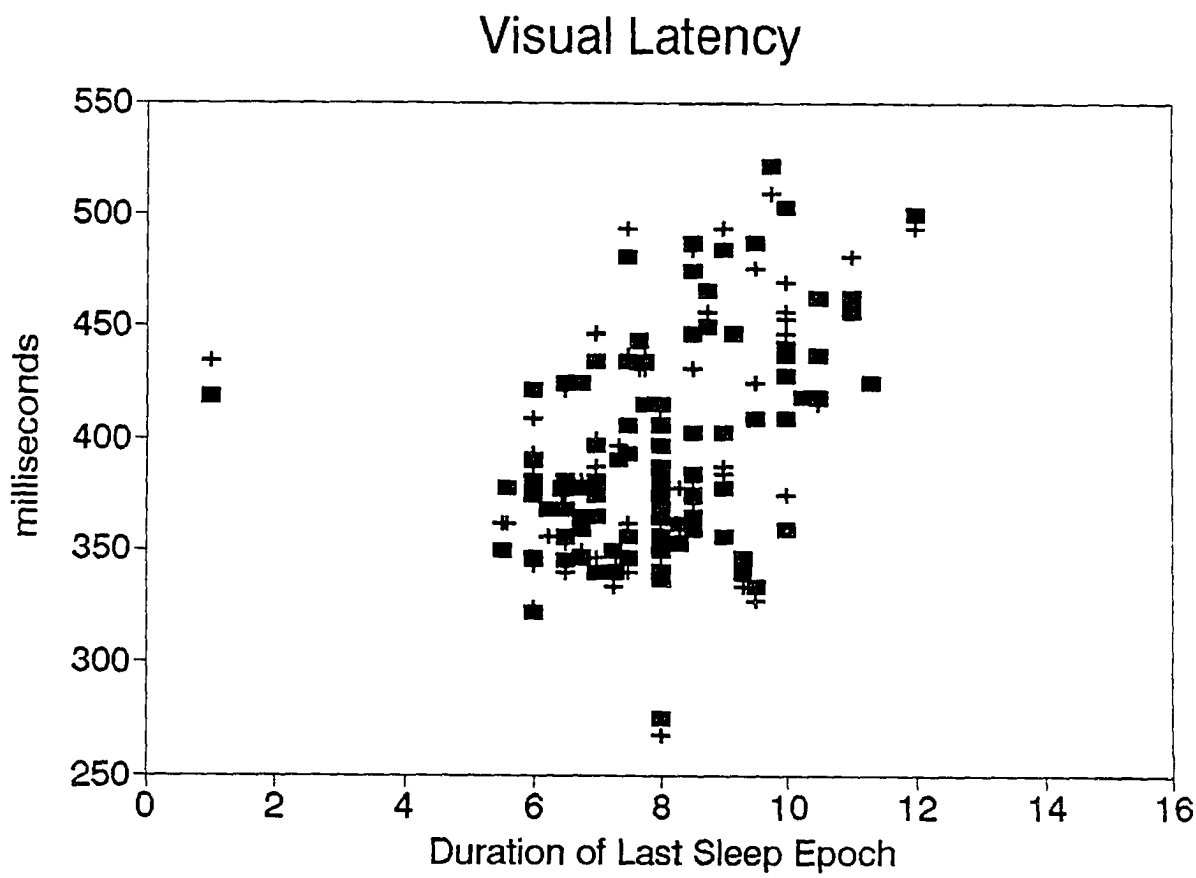


Figure 51. Subject's sleep length plotted by the photoperiod.

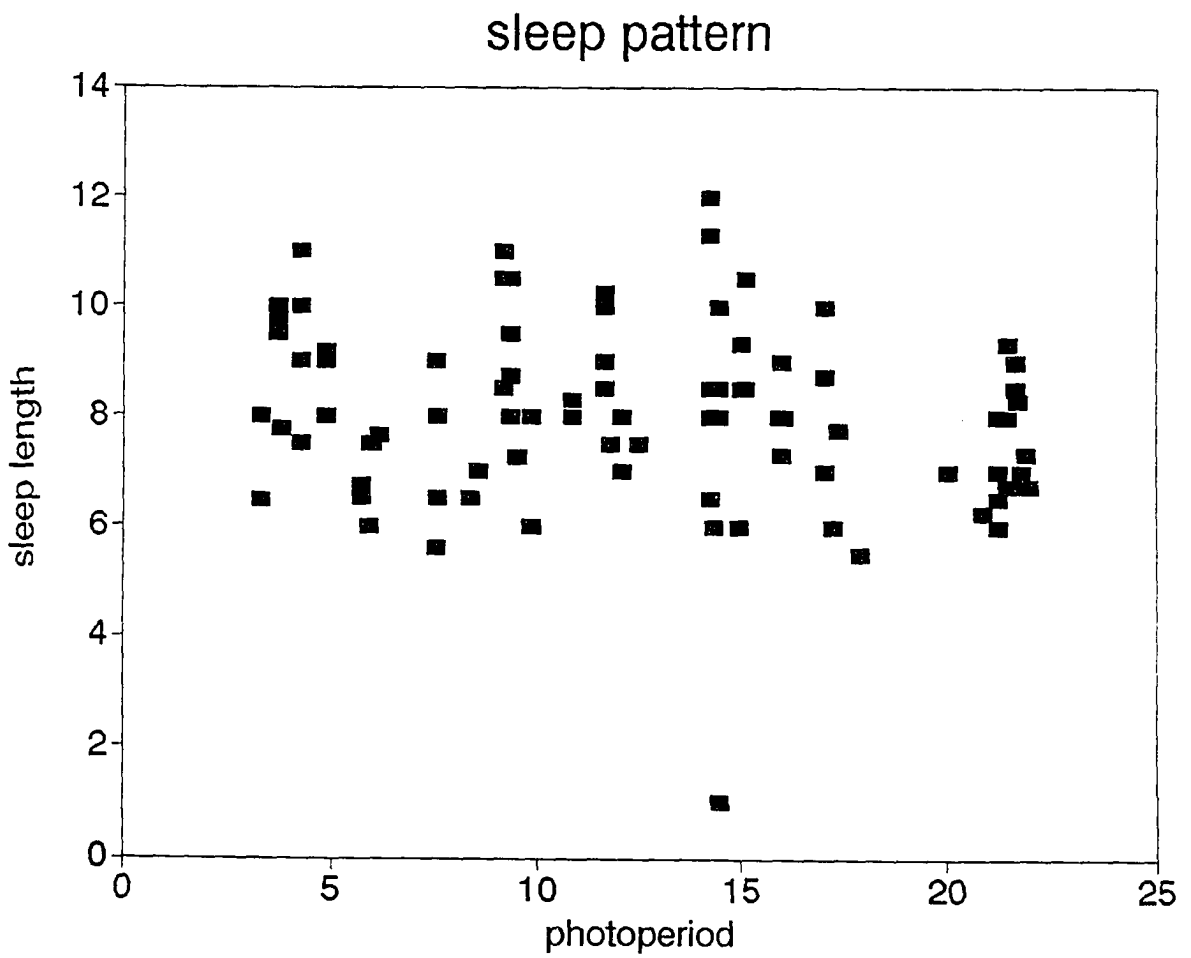
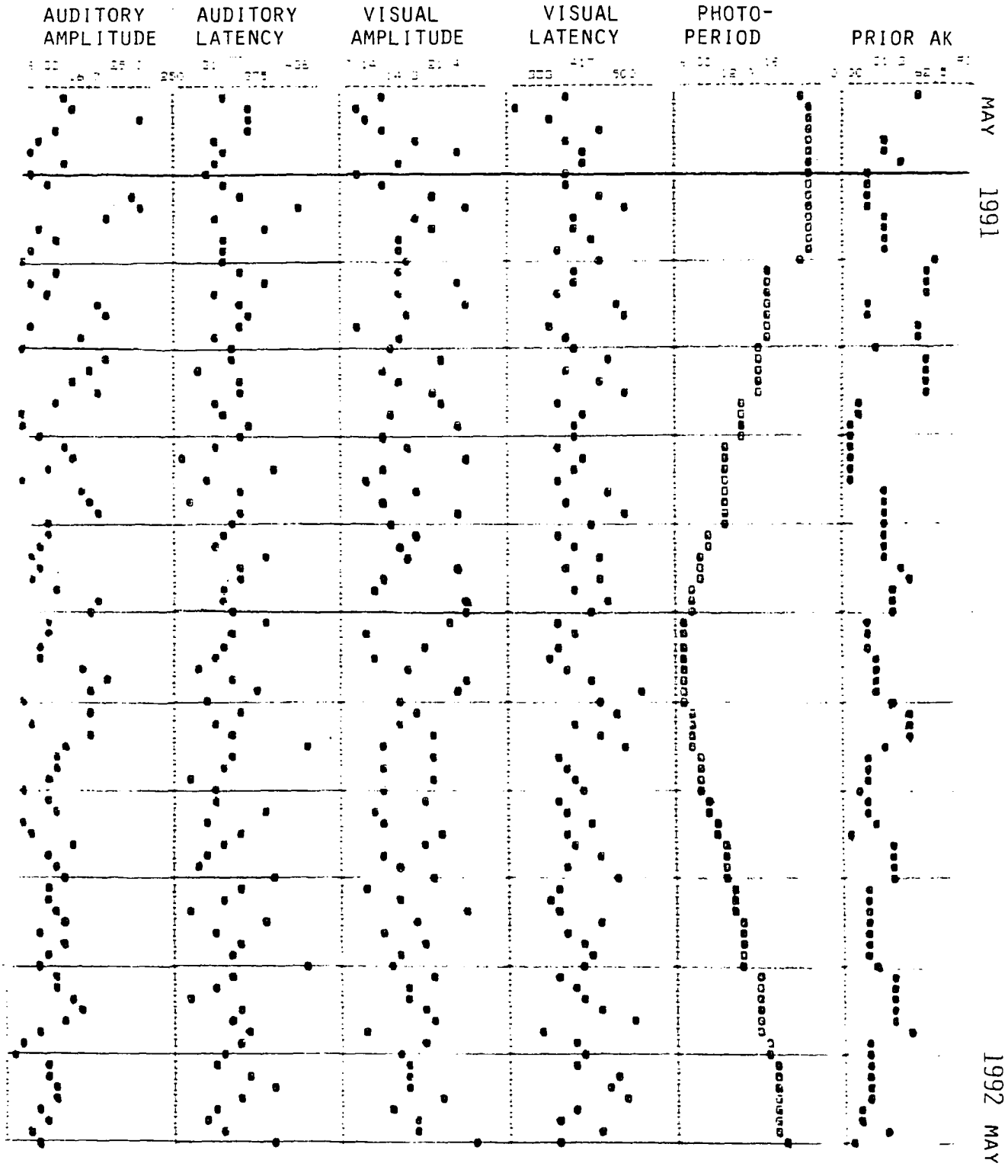


Figure 52. Time series of ERP data and environmental variables over the 12-month investigation.



Conclusions. From the principal components analysis, it is observed that one cluster of physiological variables unique to each subject (age, cranial volume, length of last sleep) explains the most variance (>24%) in the data. Over the course of 12 consecutive months of ERP testing, however, the subject's age and cranial volume were relatively stable, with age advancing 1/12 of a year each month, the minor subjects' estimated cranial volume increasing less than 1 cubic centimeter, and the adults not at all, over the course of the year. Since the variables within PCA group one are highly correlated, the findings suggest that future work is needed to distinguish those age-related differences which are developmental (Kurtzberg, Vaughan, Courchesne, Friedman, Harter, & Putnam, 1984) or performance-related (Willerman, Schultz, Rutledge, & Bigler, 1991) from those age-related differences which may be reflecting the simply the effects of an increased body size.

From the principal components analysis it is also observed that the second cluster of variables, which explain 20% of the data variance, were common experiences for all subjects and could be termed "environmental" since this group contains the geomagnetic field strength and the photoperiod. Since the purpose of the present investigation was to study the effects of the high latitude environment on the variability of event-related potentials, the factors in the environmental cluster are considered separately in experiments seven and eight.

# EXPERIMENT SEVEN

## Effect of Photoperiod-based Season in the 12-month ERP Data at High Latitude.

Bush, A. M., Geist, C. R., & Emery, S.

## EXPERIMENT SEVEN

### Effect of Photoperiod-based Season in the 12-month ERP Data at High Latitude.

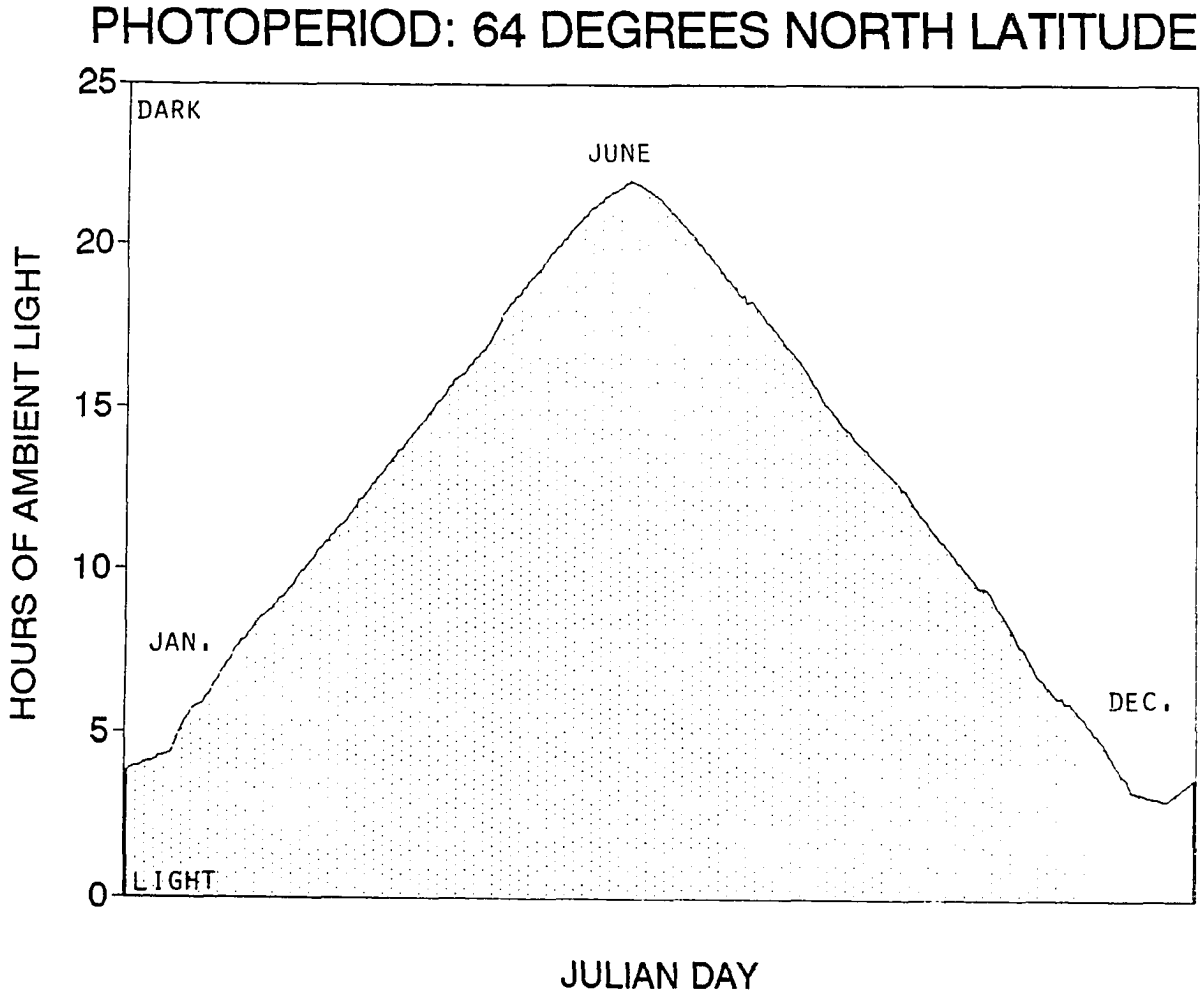
The initial analysis of variance on the 12-month ERP data demonstrated a significant month effect, although pairwise comparisons failed to identify any one month as significantly different. Considering the report of seasonal changes in the EEG (Anderson, et al., 1984), the increased visual P3 amplitude response to phototherapy (Duncan, & Rosenthal, 1986), and reports that P3 varies with light and season (Deldin, Duncan, & Miller, 1989a; 1989b), the initial investigation of the month effect addressed the considerable variation in photoperiod experienced at high latitude where the ERP data were collected. In this geographic locale (64 degrees North), photoperiod ranges from 3.2 hours in December to 21.98 hours in June (Figure 53).

The purpose of this investigation was to determine if the month effect observed could be interpreted as a response to seasonal changes in photoperiod.

Ho: ERP characteristics do not differ among four photoperiod-defined seasons.

Ha: At least one ERP characteristic differs in at least one season.

Figure 53. Graphical presentation of the ambient photoperiod variability during the 12-month period of ERP recording.



Data. The ERP data were those obtained from the longitudinal study group at high latitude, during the full 12-months of photoperiod variability as shown in Figure 53. Scatterplots show the ERP data by photoperiod for auditory P3 amplitude (Figure 54), visual P3 amplitude (Figure 55), auditory P3 latency (Figure 56), and visual P3 latency (Figure 57). Since the data obtained in recordings from left and right side of the subject's head were highly correlated ($r > 0.90$) the two values were averaged prior to grouping the data by season using a photoperiod-based definition.

DEFINITION OF SEASON:

| Name | Solar Definition | Maximum Photoperiod |
|---|---|---|
| Summer | summer solstice +/- 1 calendar month | 21.39 hours |
| Fall | autumnal equinox +/- 1 calendar month | 12.00 hours |
| Winter | winter solstice +/- 1 calendar month | 3.68 hours |
| Spring | vernal equinox +/- 1 calendar month | 12.00 hours |

ERP data grouped by season is graphically shown for auditory P3 amplitude (Figure 58), visual P3 amplitude (Figure 59), auditory P3 latency (Figure 60), and visual P3 latency (Figure 61).

Results. BMDP (Dixon, 1990) subroutine 7D was used to perform the analysis of variance. No significant difference in the seasonal means was detected for auditory amplitude ($F = 0.94$, $p = 0.4248$), visual amplitude ($F = 0.24$,

Figure 54. Auditory P3 amplitude plotted against photoperiod.

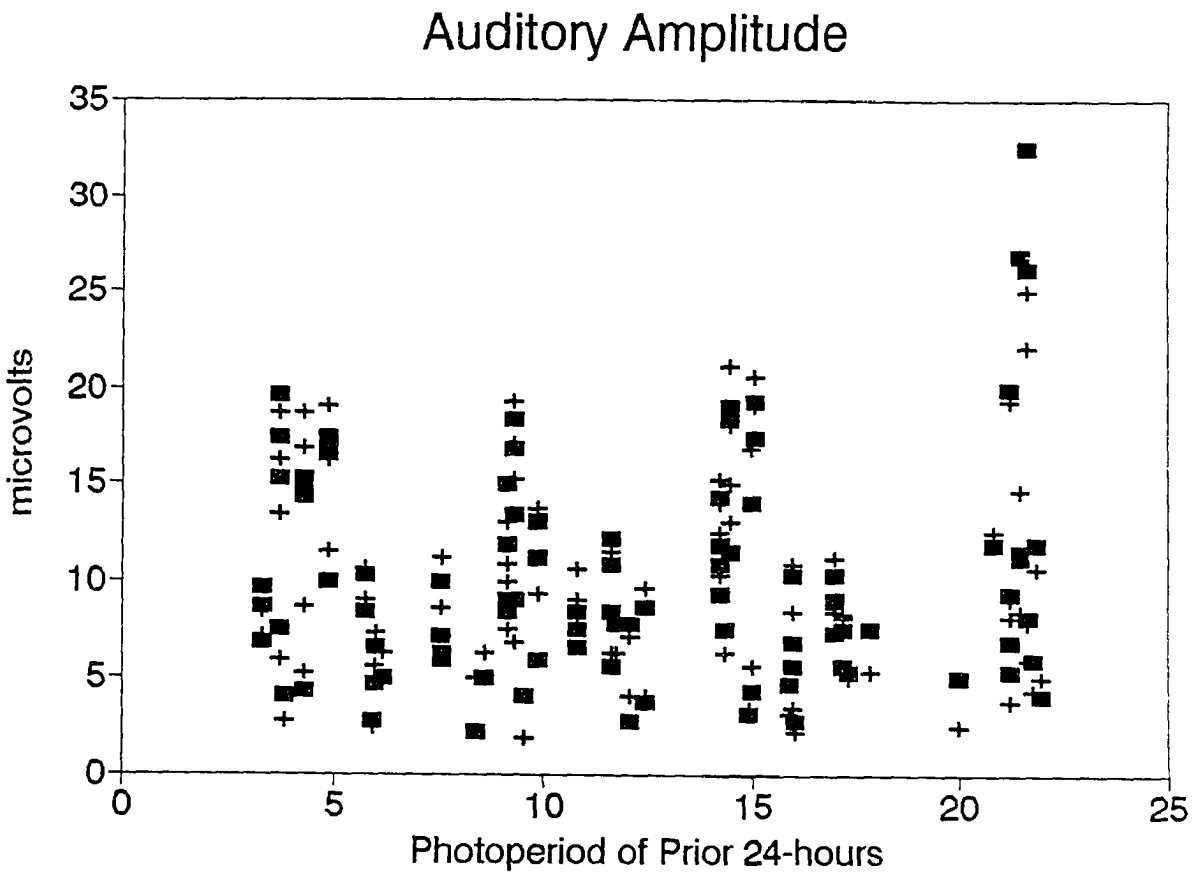


Figure 55. Visual P3 amplitude plotted against photoperiod.

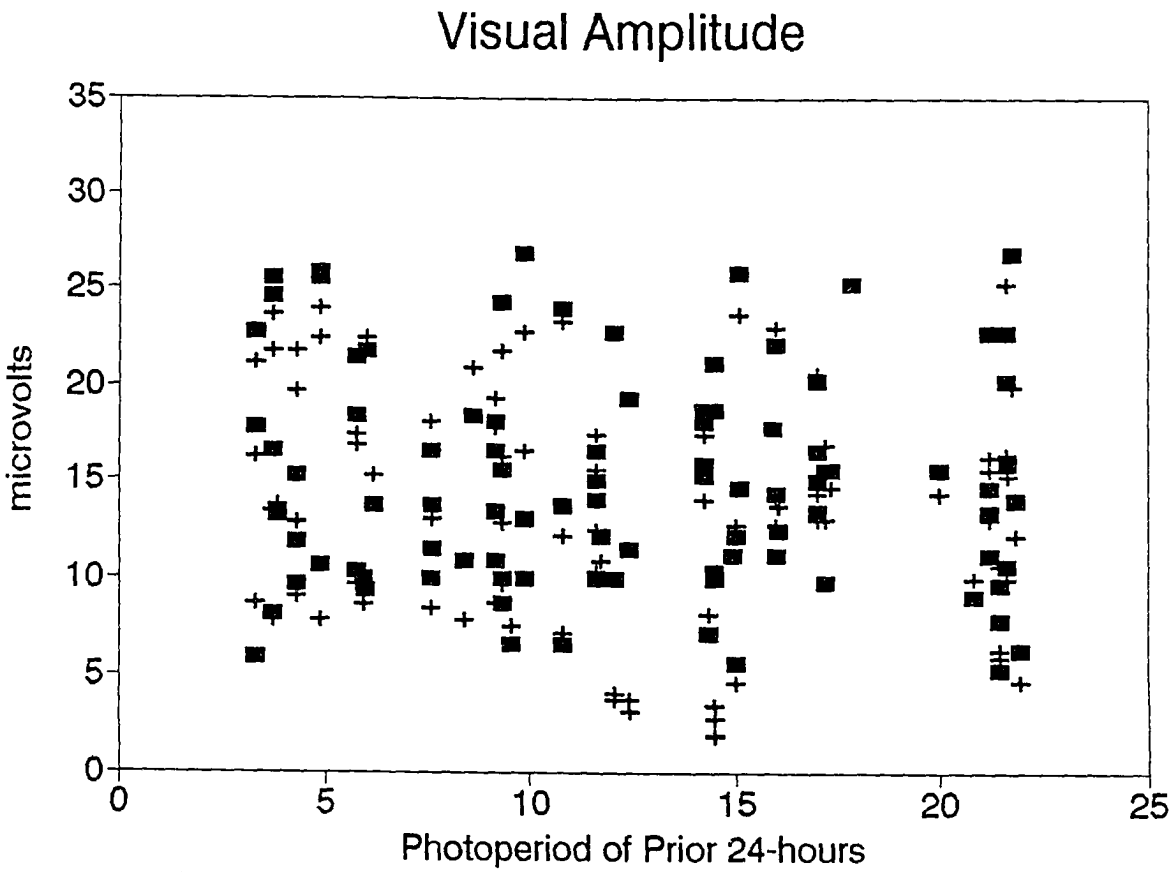


Figure 56. Auditory P3 latency plotted against photoperiod.

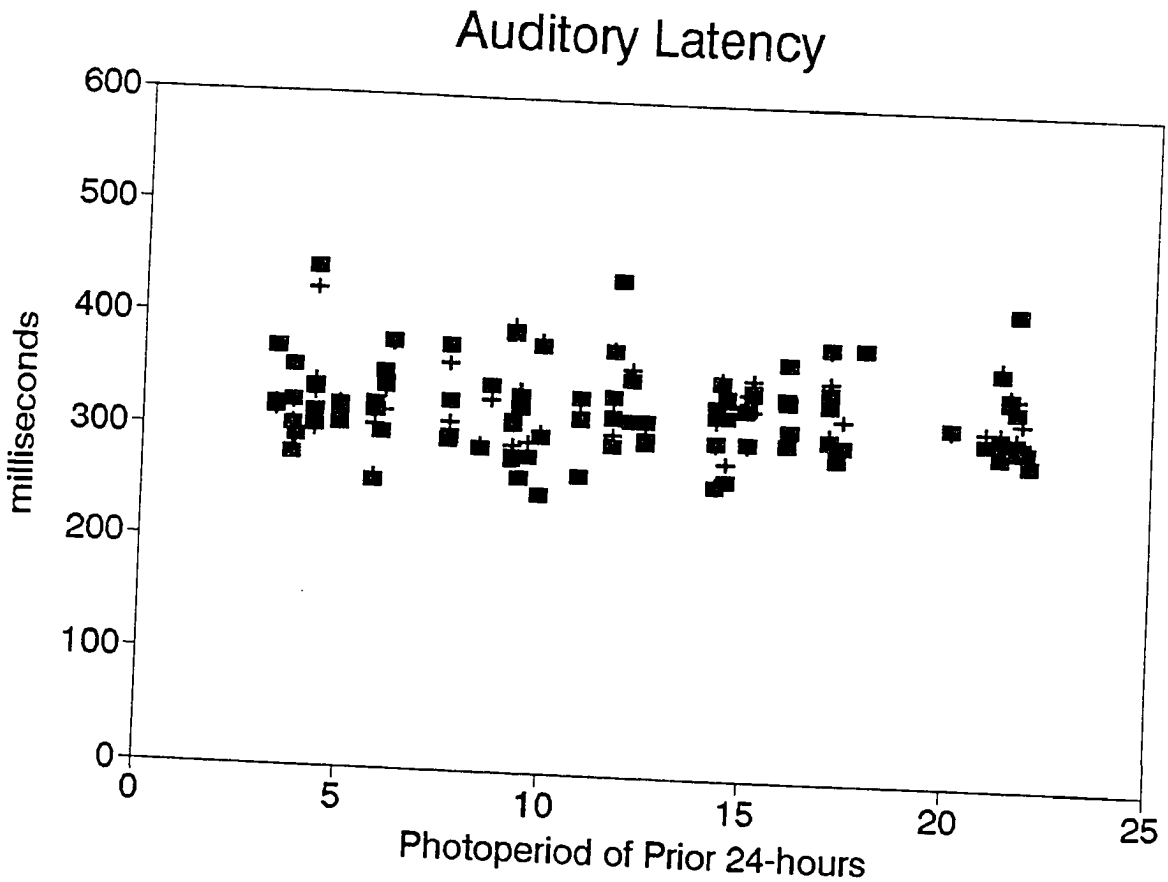


Figure 57. Visual P3 latency plotted against photoperiod.

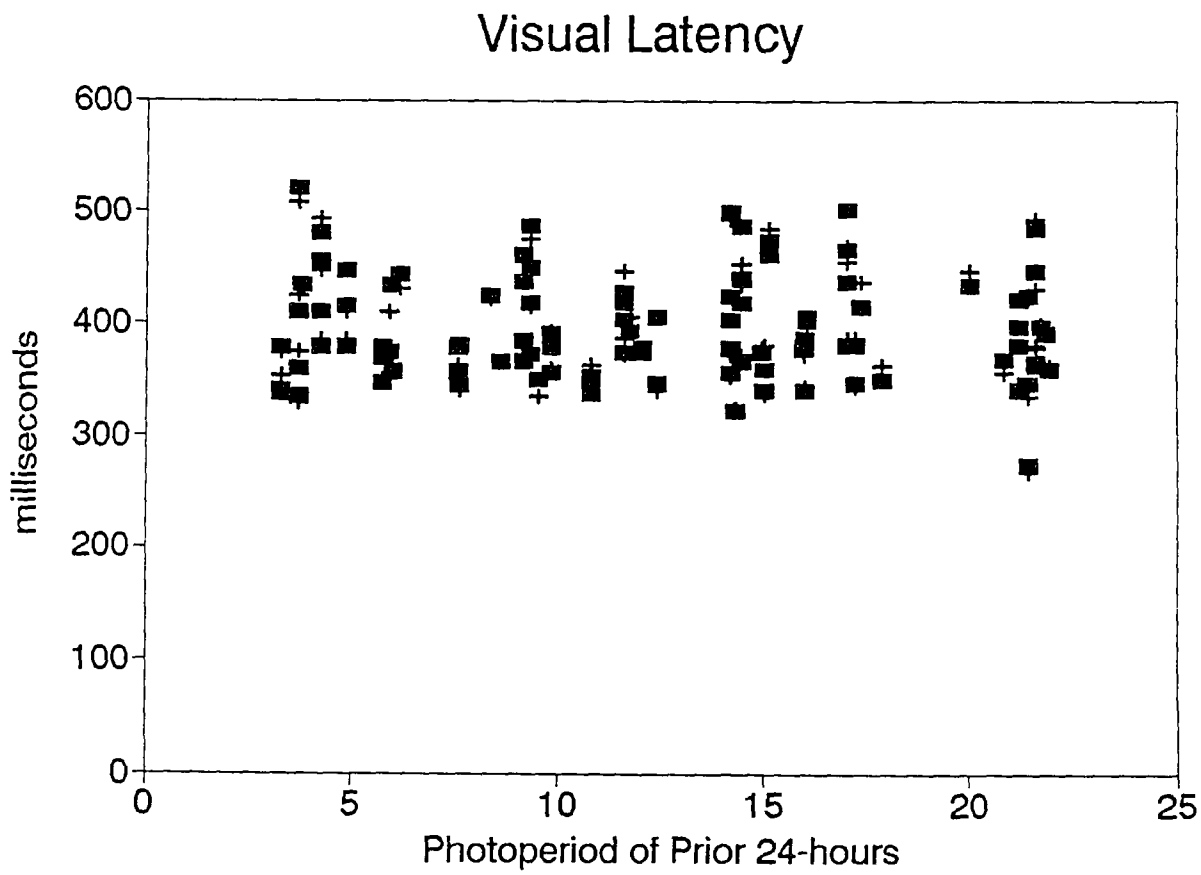


Figure 58. Auditory P3 amplitude grouped by photoperiod-based definition of season.

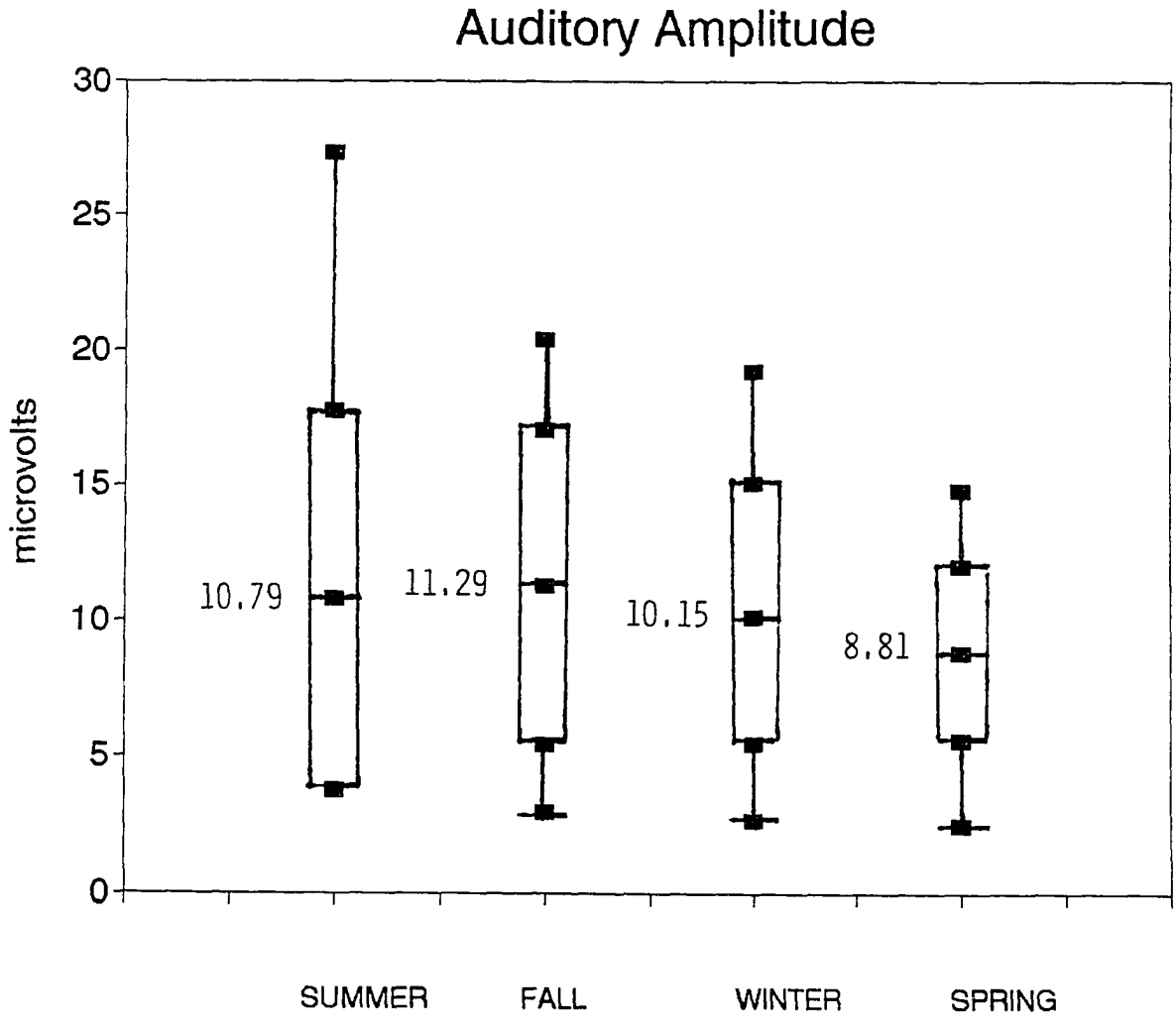


Figure 59. Visual P3 amplitude grouped by photoperiod-based definition of season.

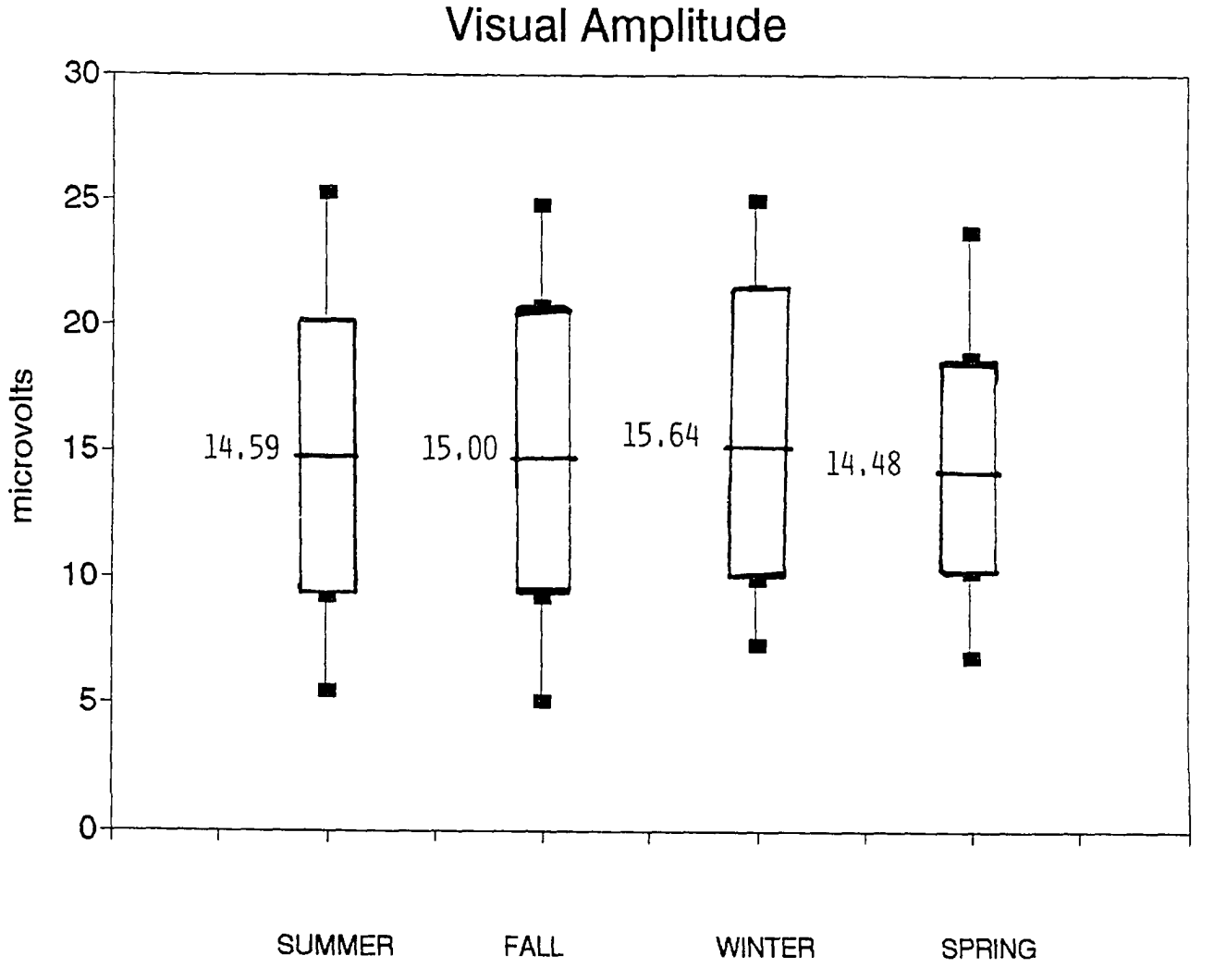


Figure 60. Auditory P3 latency grouped by photoperiod-based definition of season.

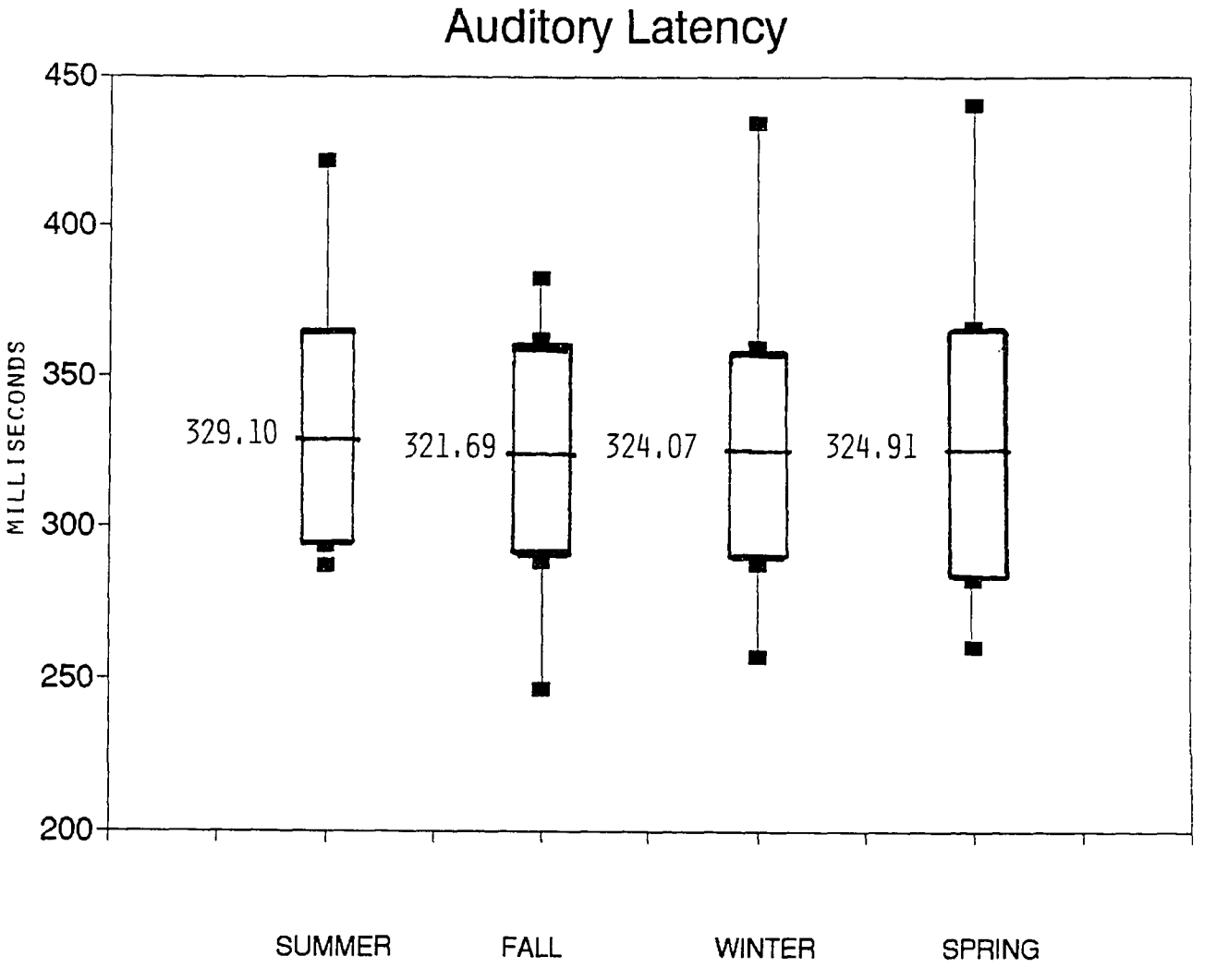
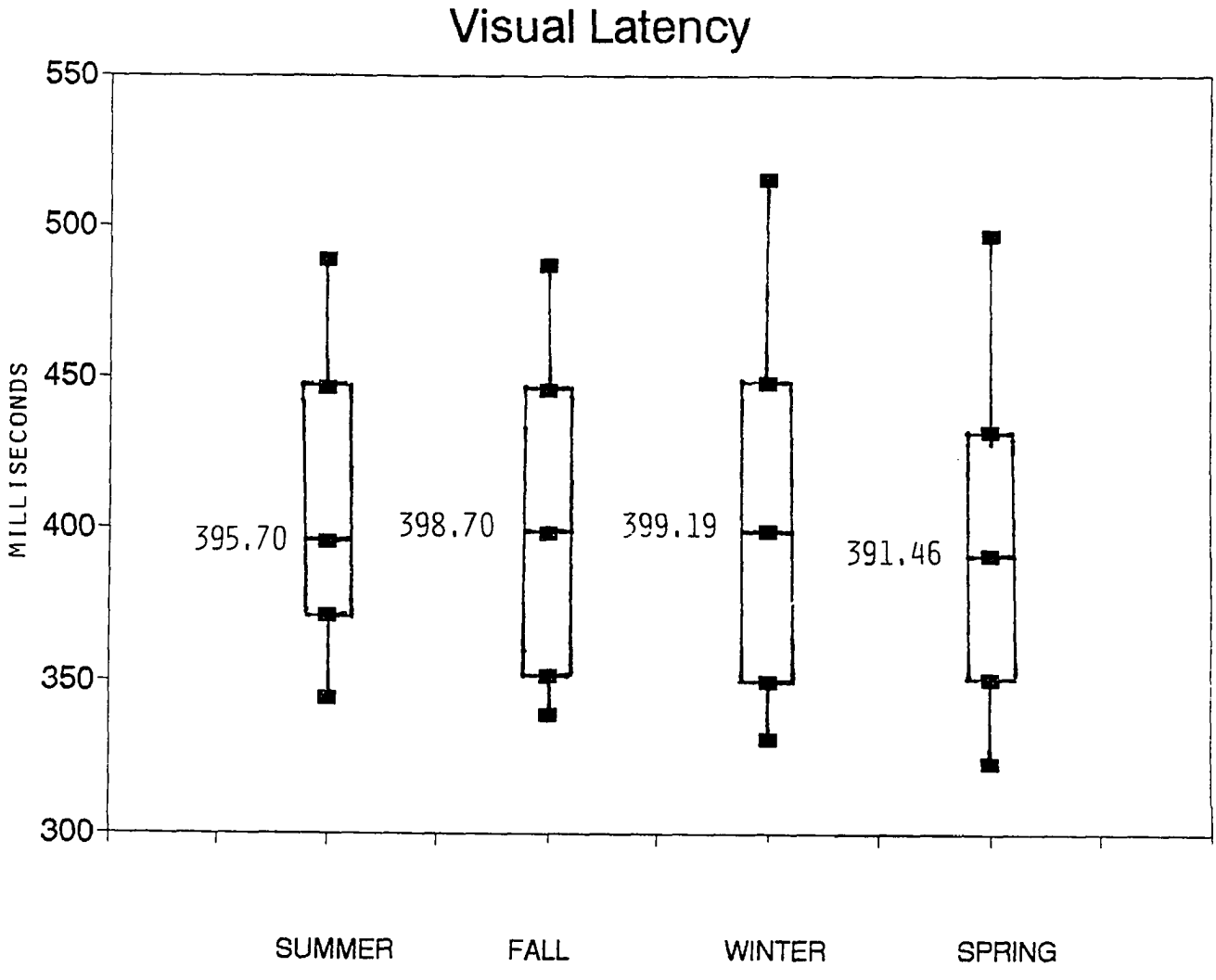


Figure 61. Visual P3 latency grouped by photoperiod-based definition of season.



p = 0.8713), auditory latency (F = 0.17, p = 0.9146), or for visual latency (F = 0.14, p = 0.9384). Pairwise comparisons with Tukey's HSD did not follow the ANOVA since no seasonal differences were detected in the mean response values of the event-related potentials.

Conclusions. The ERP responses do not differ significantly among the four photoperiod-defined seasons, thus, the month effect observed in the longitudinal study of humans at high latitude cannot be reasonably interpreted as a response to changing photoperiod. These findings do not support the conclusion of Deldin et al, (1989a) that P3 varies with light, and the findings also do not support the conclusion of Deldin et al., (1989b) that P3 varies by photoperiod-defined season. In future studies of the effect of light on event-related potential variability, consideration of employing personal photoperiod meters (e.g., lapel badges) would be helpful to more accurately quantify the intensity and/or duration of the subject's light exposure.

# EXPERIMENT EIGHT

## Effect of Geomagnetic Field Strength Variation on the 12-month ERP Data Recorded at High Latitude.

Bush, A. M., Geist, C. R., Hunsucker, R. D., & Townsend, J. B.

## EXPERIMENT EIGHT

### Effect of Geomagnetic Field Strength Variation in the 12-Month ERP Data at High Latitude.

Earlier reports (Friedman, Becker, & Bachman, 1963; 1965) have linked changes in the Earth's geomagnetic field strength with changes in human behavior. An opportunistic study was conducted (Appendix A, Figures A-1 through A-3) recording event-related potentials during a solar-flare-induced goemagnetic storm at this location which has suggested the possibility that humans may be sensitive to changes in the geomagnetic field and that this sensitivity could, perhaps, be studied with ERP methods. It is acknowledged from the start that the sensory apparatus for such an effect is unknown, and its theoretical existence is doubted by many.

However, the U.S. Arctic Research Plan (1987) called for studies to investigate factors affecting human performance at high latitude, and geomagnetic field flux has been linked with changes in human behaviour (Friedman, Becker, & Bachman, 1963;1965). Moreover, both the World Health Organization, (WHO, 1987) and the Institute of

Electronics and Electrical Engineers (IEEE, 1989) have identified the need for more data concerning magnetic field effects on human biology and health. Finally, since the location of the longitudinal study (65 degrees geomagnetic North latitude) is an active natural laboratory for geomagnetic field changes, these characteristics were included as independent variables in the longitudinal study design.

The purpose of the present investigation was to determine if the month effect detected in the longitudinal ERP study could be interpreted as a response to changes in the geomagnetic field.

Ho: ERP characteristics do not vary with geomagnetic field strength.

Ha: At least one ERP characteristics varies.

Data. ERP responses were those measured in the longitudinal study group over 12 consecutive months at high latitude. Both the auditory and visual P3 amplitude and latency were considered. The geomagnetic field data was provided by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, from the College, Alaska observatory for the time coincident with ERP recordings. Only the linear value, Ak (daily equivalent amplitude) was used for this purpose, since it was weighted more heavily than photoperiod in PCA analysis, and was also in the second cluster of independent variables. Although the magnetic field strength was measured in the recording cubicle, recall

from PCA factor analysis that room strength was not weighted as heavily as was the prior 24-hour Ak, thus cubicle field strength was not considered in the present investigation.

The daily equivalent amplitudes, Ak, for the entire 12 consecutive months of ERP recording are shown in Figure 62. Recall that Ak is a linear representation of the pseudologarithmic K-indices which quantify classes of ranges deviating from the quiet day geomagnetic field, i.e., there is no true zero. The frequency of "sudden commencements" reported by the observatory (such as storms), plotted by month of ERP recording, are shown in Figure 63. The Ak values were plotted with their corresponding ERP data for auditory amplitude (Figure 64), visual amplitude (Figure 65), auditory latency (Figure 66), and visual latency (Figure 67).

The ERP data were then sorted into three groups based on geomagnetic field strength categories, as defined by Ak cutpoints (R. Hunsucker, personal communication, February, 1993).

| CATEGORY | Ak |
|---|---|
| Low..... | 0 - 34 |
| Moderate..... | 35 - 50 |
| High..... | > 50 |

Plots of the ERP characteristics, grouped by geomagnetic field categories, are shown for auditory

Figure 62. The daily equivalent amplitudes (Ak) of the geomagnetic field for the 12 months during which human subjects participated in auditory and visual ERP testing.

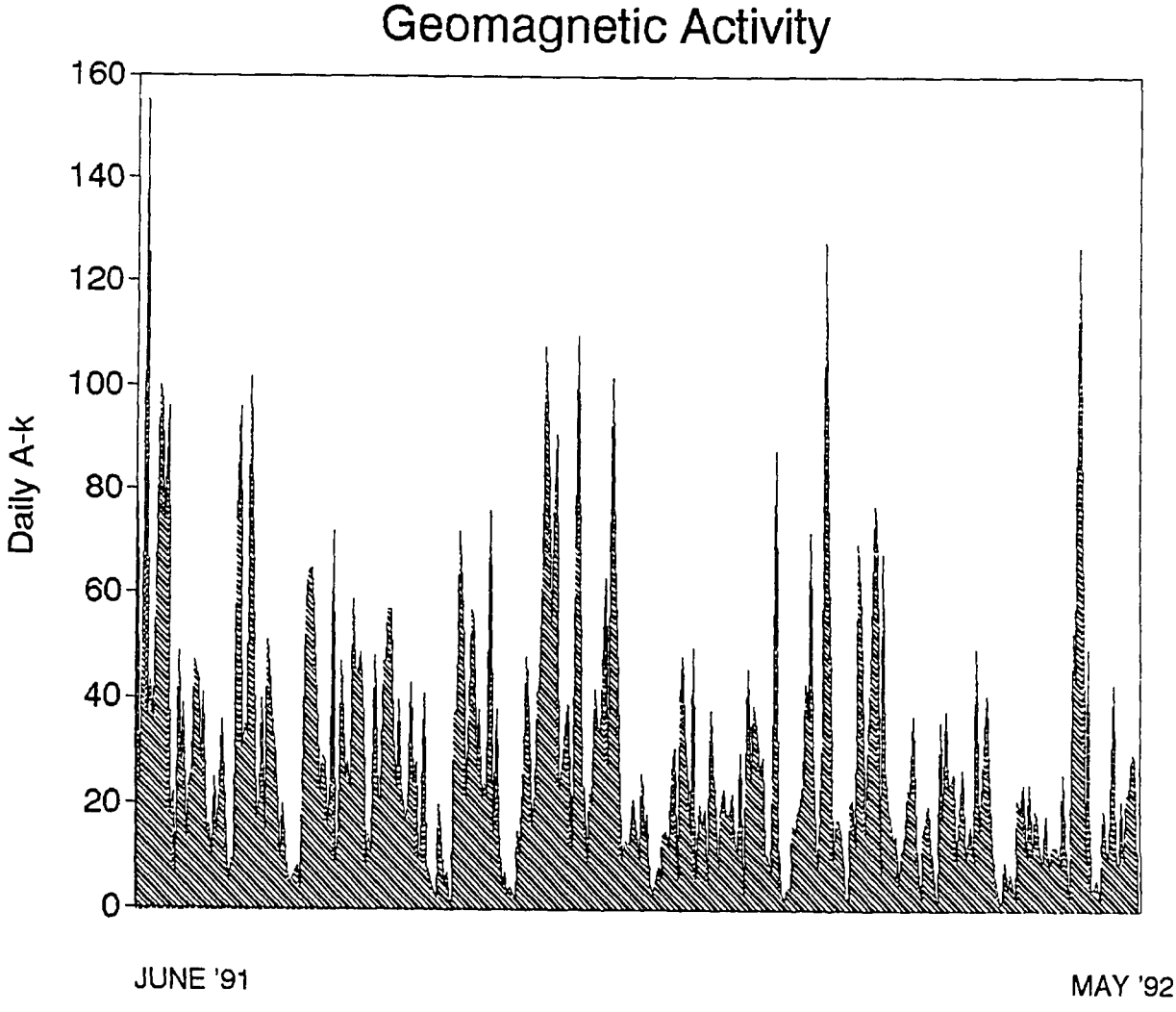
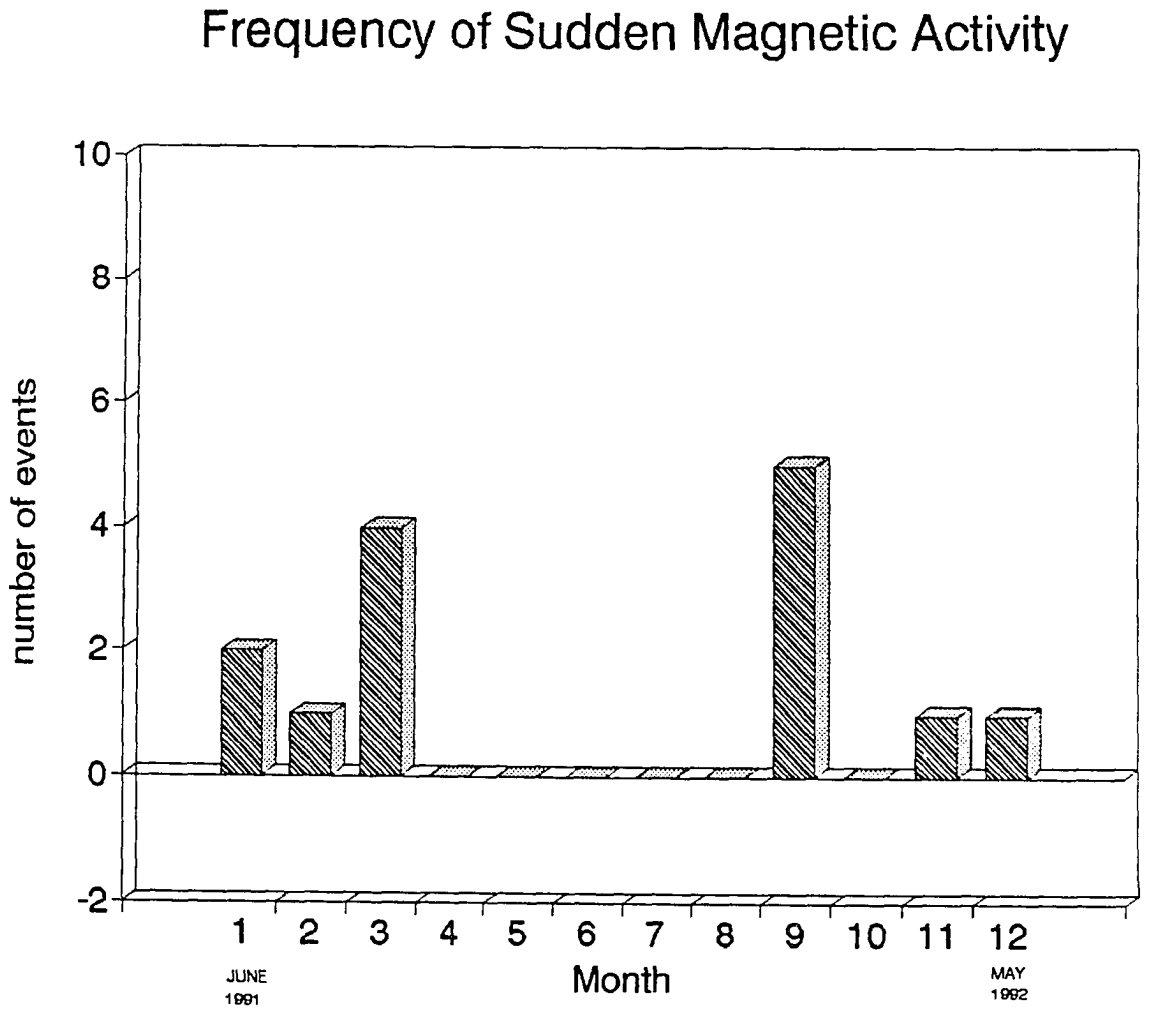


Figure 63. Frequency of sudden commencements (such as storms) during the 12-month period of human ERP testing.




DATA SOURCE: U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
N.O.A.A. FORM 76-133
COLLEGE OBSERVATORY, FAIRBANKS, ALASKA
JOHN B. TOWNSEND, CHIEF

Figure 64. Auditory P3 amplitude plotted against the daily equivalent amplitude (Ak).

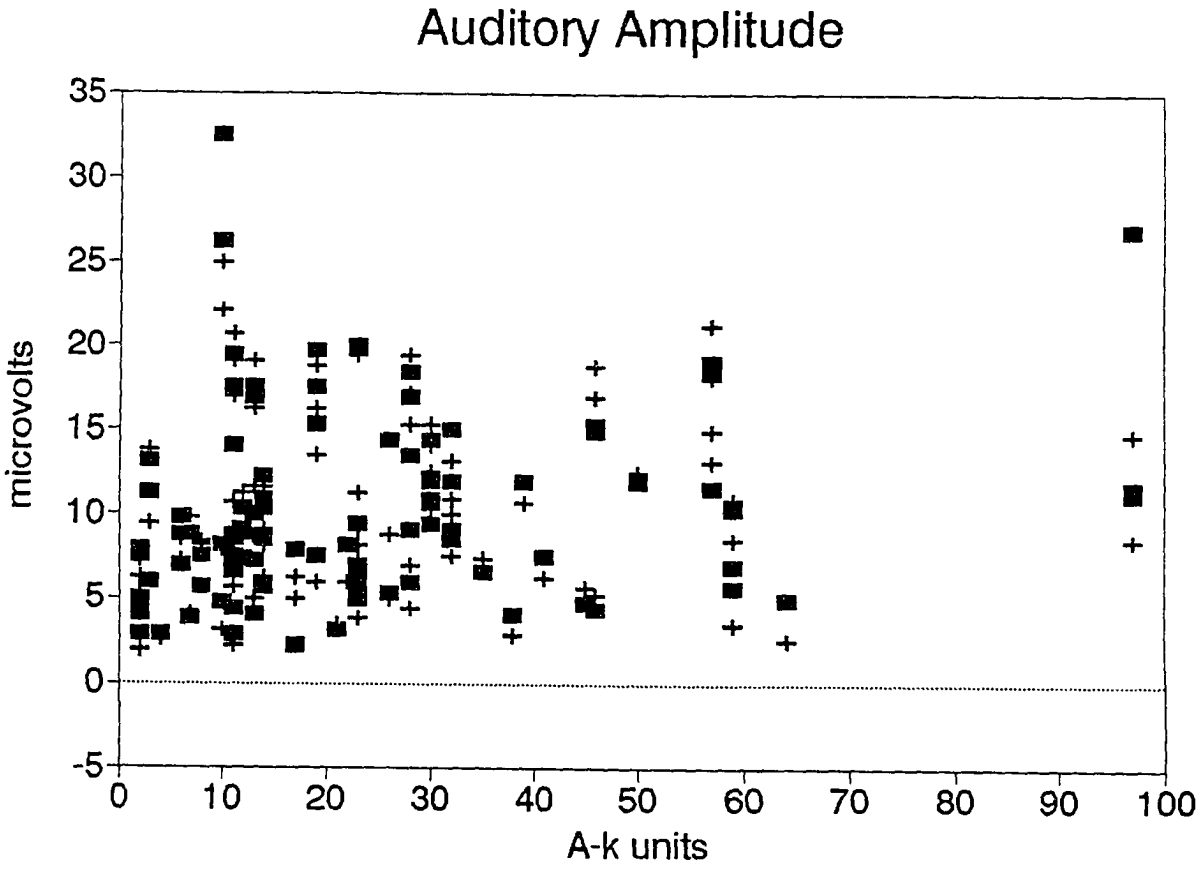


Figure 65. Visual P3 amplitude plotted against the daily equivalent amplitude (Ak).

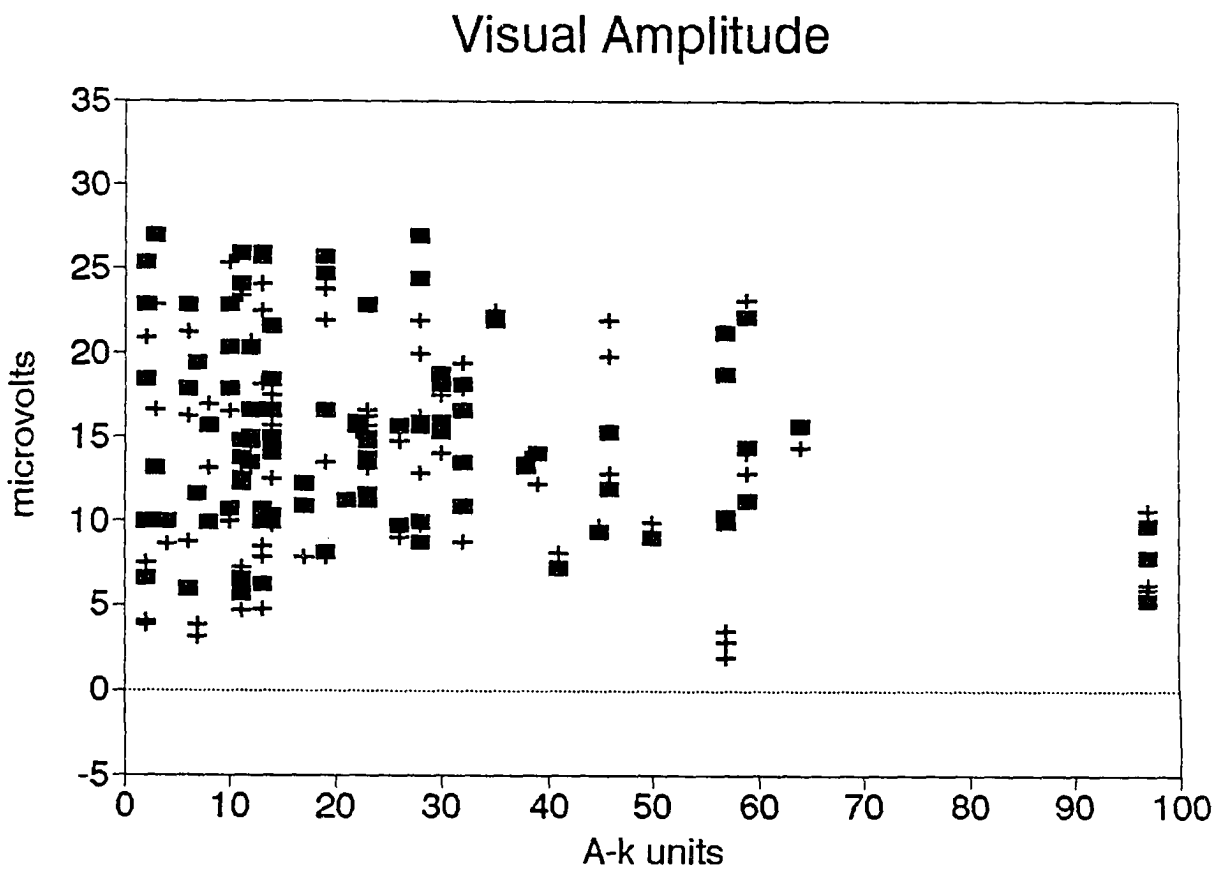


Figure 66. Auditory P3 latency plotted against the daily equivalent amplitude (Ak).

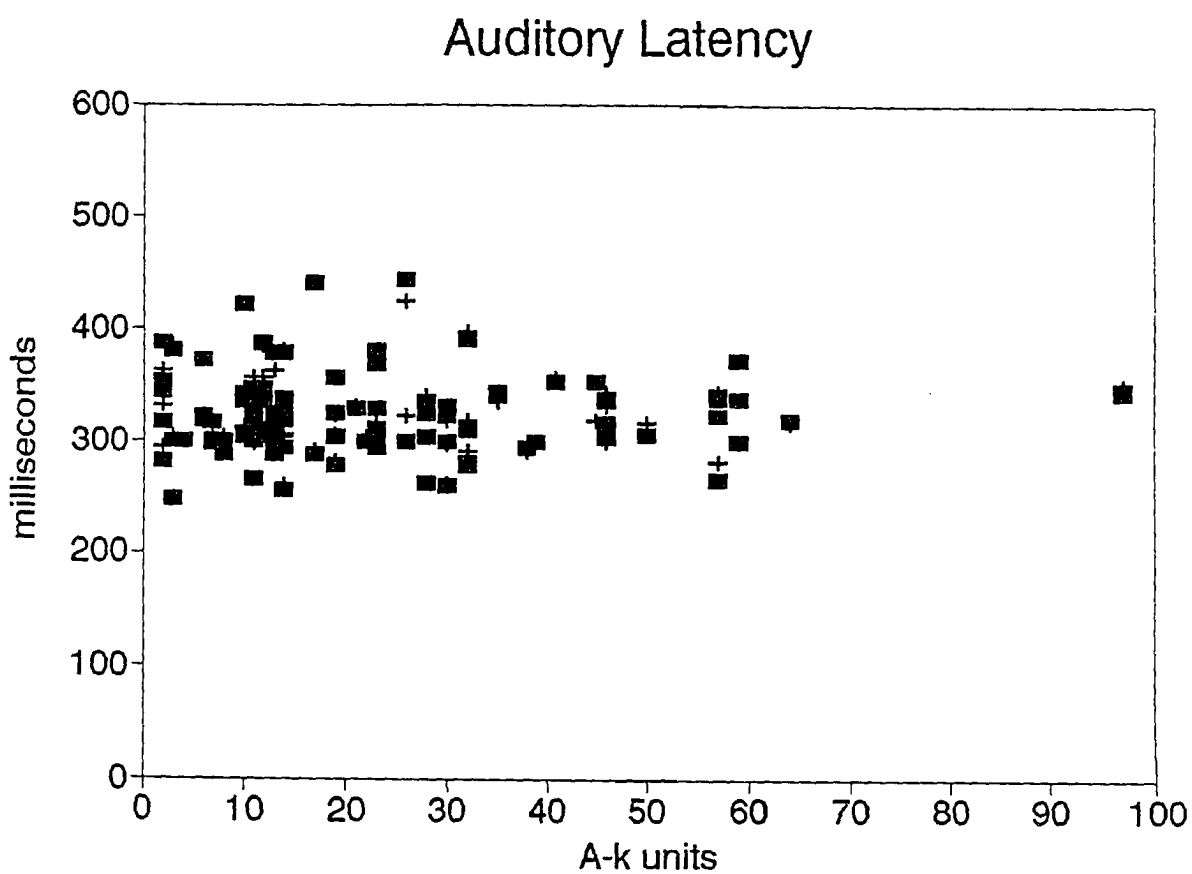
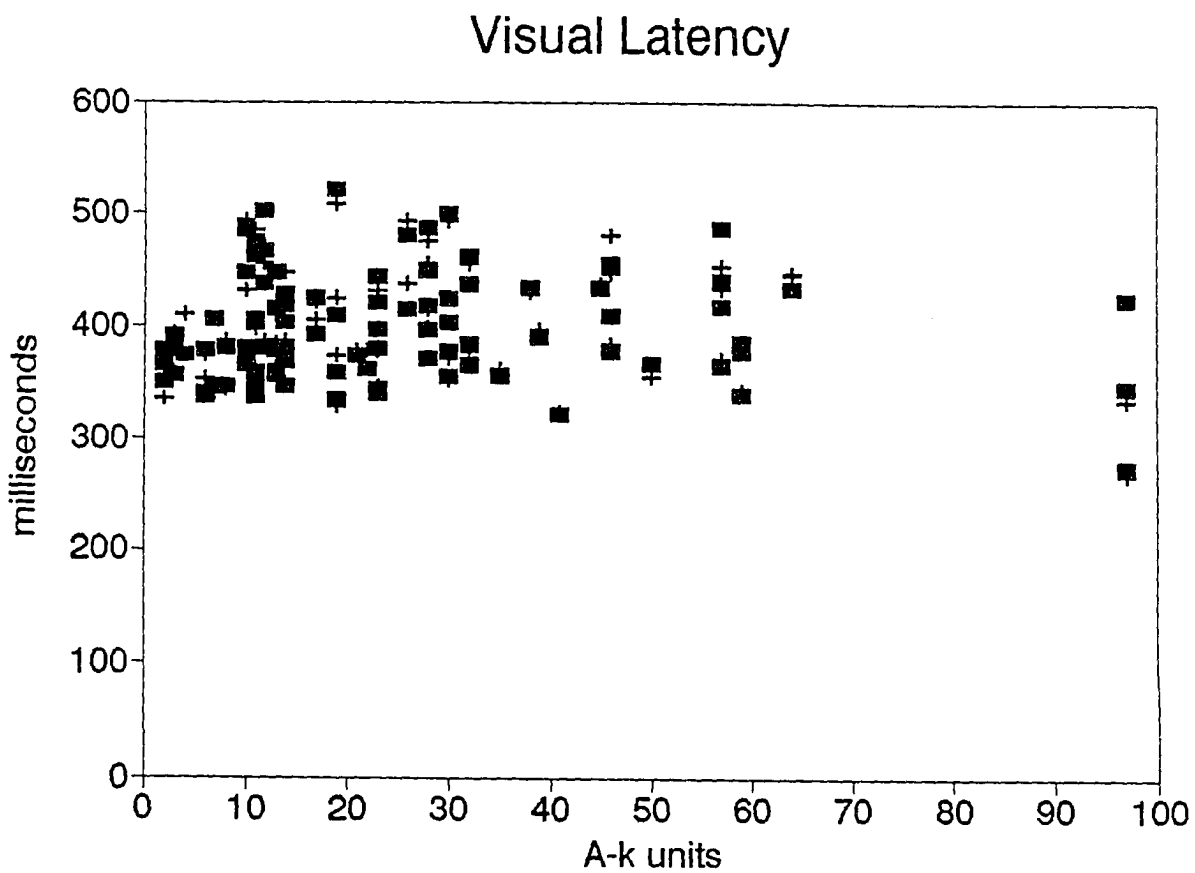


Figure 67. Visual P3 latency plotted against the daily equivalent amplitude (Ak).



amplitude (Figure 68), auditory latency, (Figure 69), visual amplitude (Figure 70), and visual latency (Figure 71).

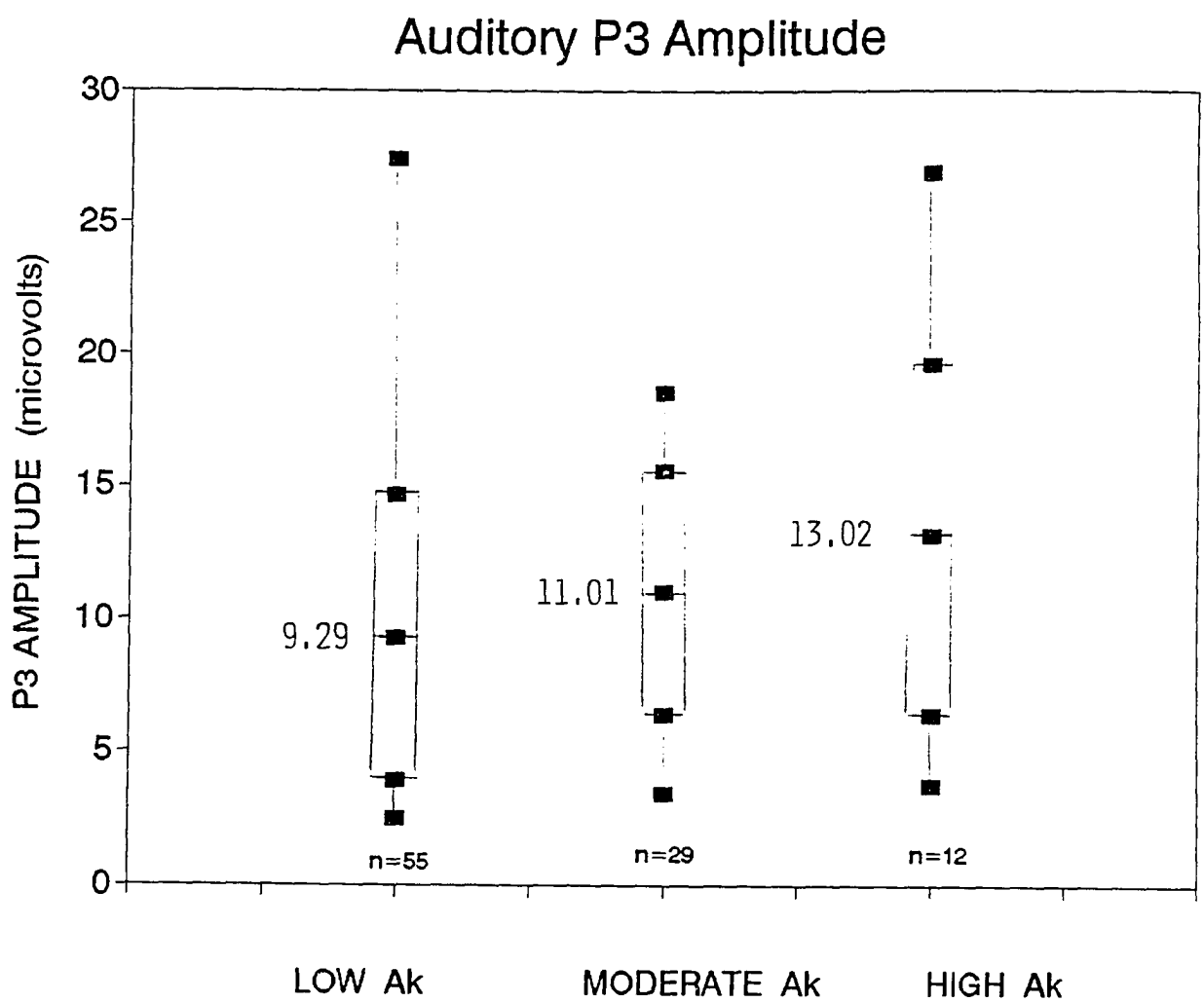
Results. BMDP (Dixon, 1990) subroutine 7D was used for analysis of variance. The difference in mean auditory amplitude was significant at alpha = 0.10 ($F = 2.82$, $p = 0.0649$) but not at alpha = 0.05. Pairwise comparison by Tukey's HSD method identified the mean auditory P3 amplitude recorded during the low field strength period as differing from the mean auditory P3 amplitude recorded during the high field strength period.

The remaining ERP characteristics did not differ significantly between the groups: visual P3 amplitude [$F(2,93) = 0.72$, $p = 0.4876$], auditory P3 latency [$F(2,93) = 0.35$, $p = 0.7077$], and visual P3 latency [$F(2,93) = 2.08$, $p = 0.1305$].

Conclusions. On the basis of data obtained and the analyses used, it is concluded that the ERP characteristic of auditory P3 amplitude differs during periods of low geomagnetic field strength compared to periods of high geomagnetic field strength.

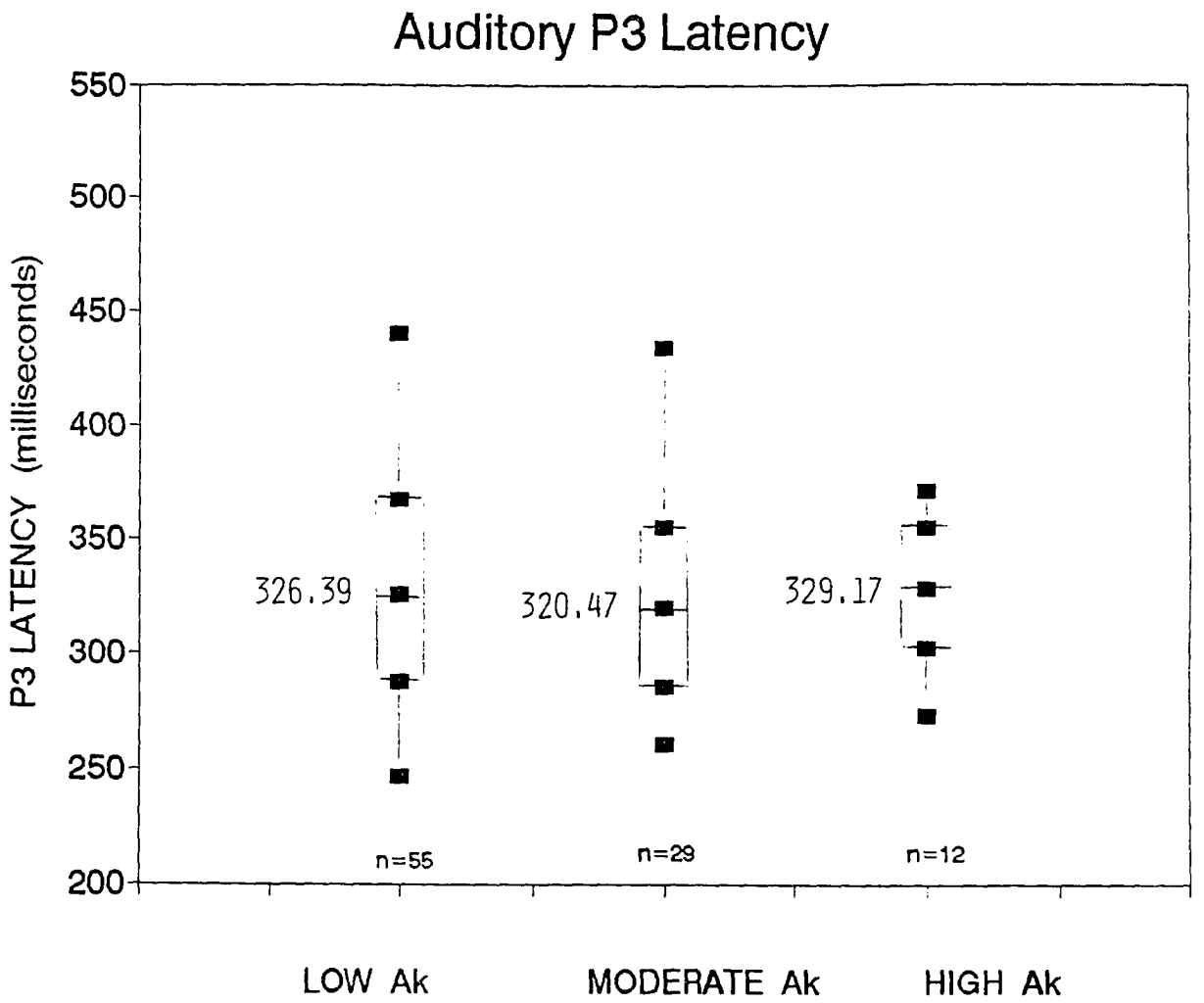
Such findings would tend to support the suggestion put forth at the Sixth International Symposium on Circumpolar Health, by Louis Rey, President of the International Arctic Committee: "it is more than likely that the strong magnetic disturbances which occur around the geomagnetic poles and

Figure 68. Grouping of auditory P3 amplitude using daily equivalent amplitude criteria.



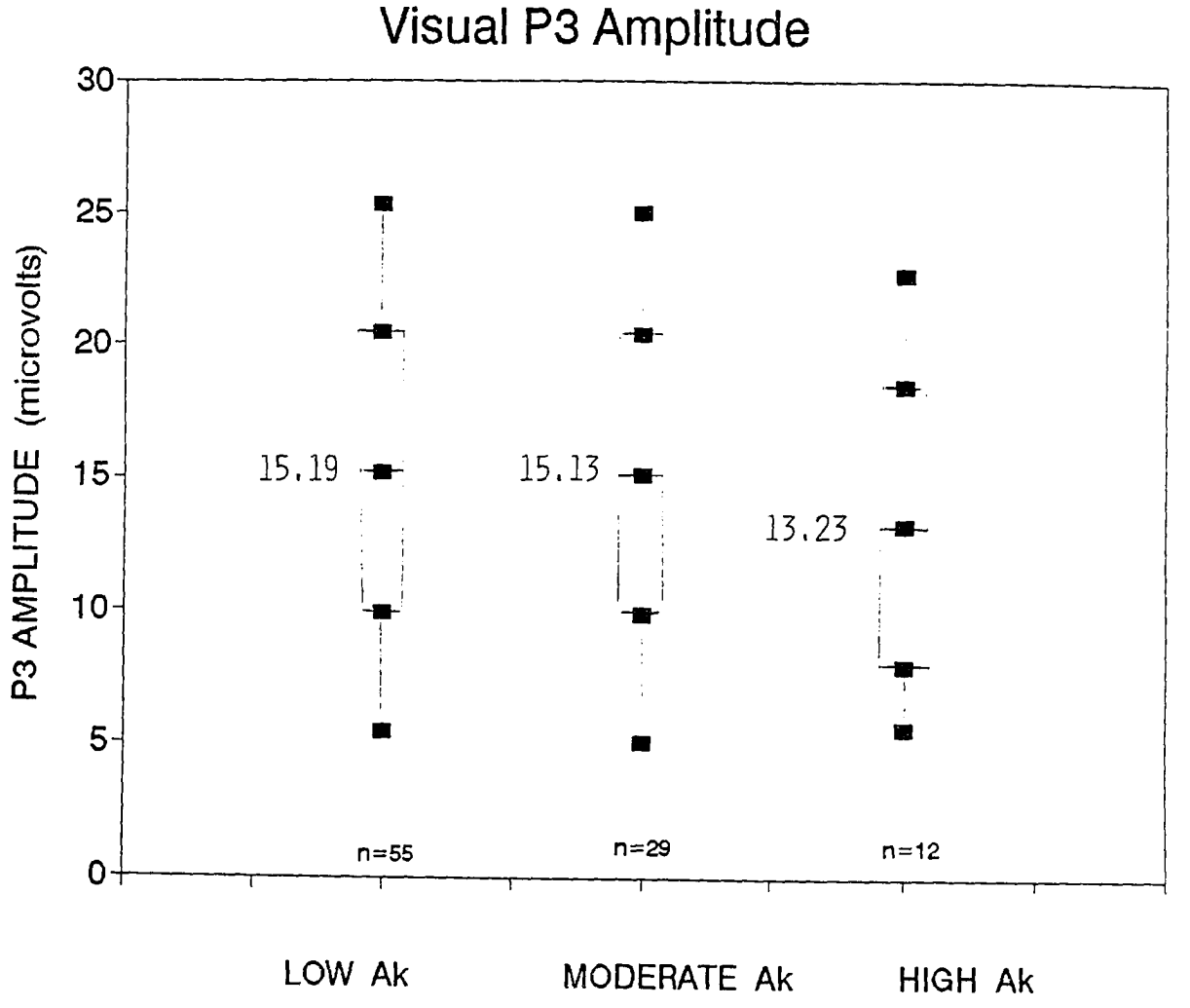

| ANALYSIS OF VARIANCE TABLE FOR MEANS | | | | | |
|---|---|---|---|---|---|
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | TAIL PROBABILITY |
| season | 159.0480 | 2 | 79.5240 | 2.82 | 0.0649 |
| ERROR | 2625.0833 | 93 | 28.2267 | | |
| EQUALITY OF MEANS TESTS; VARIANCES ARE NOT ASSUMED TO BE EQUAL | | | | | |
| WELCH | | 2, 28 | | 2.27 | 0.1222 |
| BROWN-FORSYTHE | | 2, 30 | | 2.43 | 0.1050 |
| LEVENE'S TEST FOR VARIANCES | | 2, 93 | | 0.60 | 0.5535 |

Figure 69. Grouping of auditory P3 latency using daily equivalent amplitude criteria.



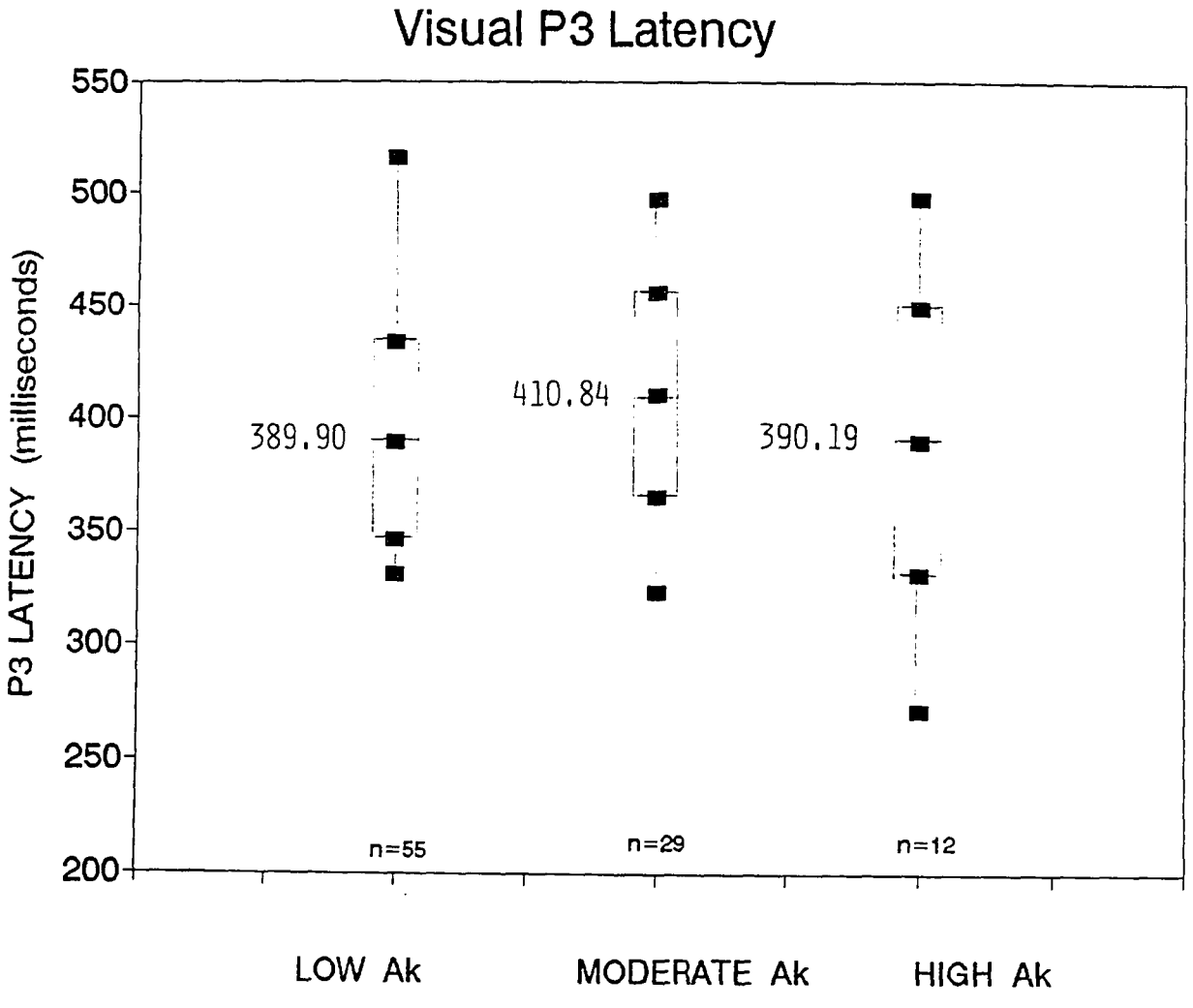

| ANALYSIS OF VARIANCE TABLE FOR MEANS | | | | | TAIL |
|---|---|---|---|---|---|
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROBABILITY |
| season | 908.9268 | 2 | 454.4634 | 0.35 | 0.7077 |
| ERROR | 121772.1674 | 93 | 1309.3781 | | |
| EQUALITY OF MEANS TESTS; VARIANCES ARE NOT ASSUMED TO BE EQUAL | | | | | |
| WELCH | | 2, 35 | | 0.42 | 0.6580 |
| BROWN-FORSYTHE | | 2, 66 | | 0.44 | 0.6475 |
| LEVENE'S TEST FOR VARIANCES | | 2, 93 | | 1.23 | 0.2972 |

Figure 70. Grouping of visual P3 amplitude using daily equivalent amplitude criteria.




| ANALYSIS OF VARIANCE TABLE FOR MEANS | | | | | TAIL |
|---|---|---|---|---|---|
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROBABILITY |
| season | 40.0535 | 2 | 20.0267 | 0.72 | 0.4876 |
| ERROR | 2573.1673 | 93 | 27.6685 | | |
| EQUALITY OF MEANS TESTS; VARIANCES ARE NOT ASSUMED TO BE EQUAL | | | | | |
| WELCH | | 2, 30 | | 0.71 | 0.5006 |
| BROWN-FORSYTHE | | 2, 44 | | 0.72 | 0.4901 |
| LEVENE'S TEST FOR VARIANCES | | 2, 93 | | 0.02 | 0.9821 |

Figure 71. Grouping of visual P3 latency using daily equivalent amplitude criteria.




| ANALYSIS OF VARIANCE TABLE FOR MEANS | | | | | |
|---|---|---|---|---|---|
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | TAIL PROBABILITY |
| season | 8831.6670 | 2 | 4415.8335 | 2.08 | 0.1305 |
| ERROR | 197313.7363 | 93 | 2121.6531 | | |
| EQUALITY OF MEANS TESTS; VARIANCES ARE NOT ASSUMED TO BE EQUAL | | | | | |
| WELCH | | 2, 27 | | 2.10 | 0.1415 |
| BROWN-FORSYTHE | | 2, 30 | | 1.68 | 0.2031 |
| LEVENE'S TEST FOR VARIANCES | | 2, 93 | | 1.03 | 0.3599 |

within the auroral zone...interact with brain activities" (Rey, 1985, pg. 5). However, the mechanisms of human magnetoreception are unclear, and the practical signifance of such processes continues to be debated.

That the auditory amplitude should differ, rather than the visual amplitude, is difficult to interpret in a biological sense, as most of the working theories of human magnetoreception (Baker, 1988; Davis, 1989; Semm, 1992; Semm, et al., 1980) are converging on the retina of the eye as a likely candidate for a magnetoreceptive organ. However, the oral literature of the North has numerous anecdotal reports of persons claiming to hear the aurora (J. Kleinfeld, personal communication, September, 1992), although the sensory mechanisms for such perception (which is also not widely accepted) remain a mystery.

# DISCUSSION

# DISCUSSION

## Validity, Reliability and Comparability

Validity. The most crucial issue in test construction is validity (Groth-Marnat, 1990). The theoretical construct that P3 amplitude is sensitive to informational value (Rockstroh, et al., 1989; Miller, 1985) of the stimuli and directly related to task relevance was validated for the samples of normal humans at high latitude, using both the auditory and visual event-related potential protocols described in the laboratory methods. The concurrent criterion of having the subject count the number of oddball stimuli detected served as the outside measure of informational value of the stimuli, and all subjects capably performed the task.

As seen in experiment three, the amplitude of P3, in both sensory modalities, was significantly greater for those relevant stimuli which have informational value for the subject, e.g., those to be counted. These findings tend to support Bayles' (1982) evaluation of P3 amplitude as a marker of selective attention, as well as Nassman's (1988) conclusion that P3 amplitude varies with a subjects' discrimination among stimuli on the basis of category (e.g., high-pitched or low-pitched, large squares or small). As

seen in experiment three, the latency of P3 was also observed to change with stimuli categorization (attend, ignore) which tends to support prior observations (Kutas, McCarthy, & Donchin, 1977; McCarthy, & Donchin, 1980) that processes concerned with the categorization of stimuli similarly affect P3 latency.

These characteristics of the P3 event-related potential suggests that eventually it may prove to be a useful adjunct for investigating variables suspected to contribute to operator error in human monitoring situations, particularly where the consequences of such error have far-reaching and potentially devastating human and economic costs, e.g., manned space missions, defensive radar installations, nuclear power generating facilities, jetliner or oil tanker traffic control stations, and so forth. These findings also suggest that event-related potentials may eventually find practical application in industrial development, specifically in the design of human monitoring stations to devise consoles, panels, and the like, such that the critical monitoring elements and alarms would be designed to facilitate stimulus evaluation and discrimination by the human operator.

Reliability. As seen in experiment four, the event-related potential data, recorded with the techniques described in the laboratory methods, are reliable within the same sensory modality and between skull surface halves of the same

subject, provided the time between testings is fairly short, ten minutes or less. The predictability of the ERP results becomes increasingly unstable as the time between tests on the same subject is lengthened. While it is acknowledged that a certain degree of random "noise" will always be present due to the inevitable natural fluctuation in human performance, the significant variation in the 12 consecutive monthly recordings from the same subject over one year's time, as seen in experiment five, underscores the highly variable nature of ERP responses. The findings also illustrate the need for additional longitudinal human studies in order to more precisely discriminate natural human variation from variability which may be related to other factors.

In particular, the findings of the longitudinal investigation of normal human subjects illustrate the difficulty of attempting to interpret the results of a single ERP test, or of using ERP results to discriminate among groups by the amount of attentional resources mobilized (Duncan, & Rosenthal, 1986). There is insufficient knowledge about the ERP generator location and function to attribute quantification to the results. Indeed, our own efforts to identify a relationship between ERP characteristics and academic performance (Bush, Geist, & Emery, 1992), which relates to amounts of attentional resources mobilized, have thus far not proven successful.

Parallel Forms. As seen in experiment four, the auditory and visual protocols, while similar, provided different information about a subject and were considered as different measurements.

In practical terms, observing some quanta of change in one sensory modality, without observing a similar degree of change in the other sensory modality, may not necessarily be due to some intervening process. Rather, the differences noted may simply reflect the inherent natural differences of the two measurements. Before concluding that any intervening process, particularly the application of an experimental treatment (e.g., phototherapy or helmholz coils) is necessarily a causal agent of the modality differences observed, it is necessary to quantify the extent of inherent natural variability between the two measurements, within the research population and over the time frame of the proposed experiment. The ERP literature is conspicuously lacking in longitudinal studies of any sort, and the issues of reliability and clinical utility cannot be resolved with short-term knowledge alone.

One practical implication of the data obtained is that, should it be desirable to perform long-term monitoring of a human subject's event-related responses (such as on a space mission, or over the course of an 8-hour work shift), a large number of scalp electrodes would not be necessary unless the specific research objective were to conduct topographic mapping of scalp surface potentials, or to

investigate the extent of laterality in scalp-surface recordings under various conditions. A simple 4-electrode montage is sufficient to obtain data that may be meaningfully compared and discussed in the context of published results from the ERP literature.

## COMPARABILITY

The techniques described produce ERP recordings which resemble those reported in the literature from other facilities. Two amplitude measuring methods were evaluated in experiment one, and a selection was made based on the ability of each method to correctly identify the P3 response recorded from two nearly identical groups as not being different. The defined-baseline method was used throughout the body of the work.

As seen in experiment four, no significant differences were found between results obtained using an unlinked mastoid montage and results obtained using linked mastoids. Laterality. The data obtained by simultaneoulsy recording separately from the two sides of the head was very highly correlated. These findings differ from the significant laterality differences reported (Brigham, 1987) for the auditory P2-N2 amplitude in normal human adults. The findings also differ from the significant laterality differences reported (Harter, Aine, & Schroeder, 1984) for the visual P3 ERP amplitude recorded from the occipital

scalp surface of six subjects (age & gender not specified). The findings differ as well from the significant laterality differences reported (Aine, & Harter, 1984) in visual P3 ERP amplitude recorded from the occipital scalp surface of five adults (3 females and 2 males, ages 20-40) to stroop stimuli.

As seen in experiment six, a decrease in P3 latency was observed with increased age for both sensory modalities in the data recorded from the longitudinal study group. This differs from the age-related increase in visual P3 ERP latency reported (Lescher, 1981) for central scalp (Cz) recordings from adults ages 20-82 (gender mix not specificied), and from the age-related increase in auditory P3 ERP latency also reported (Picton, et al., 1984). The decrease in P3 latency observed in the sample from a high latitude population tends to support the similar age-related decrease in P3 latency reported by Goodin, Squires, Henderson, & Starr, (1978), Halliday, Callaway, & Lynch (1987), and Martin, et al., (1987).

Age. As seen in experiment six, the visual P3 amplitude decrease with age differs from the age-related increase reported (Lescher, 1981) for central scalp (Cz) visual ERP recordings from adults ages 20-82 (gender mix not specified). In the longitudinal sample of eight subjects, the auditory P3 amplitude was observed to decrease until about age 30 and then increased again. Although this was a small sampling of ages, this differs from the report

(Pfefferbaum, Ford, Roth, & Koppell, 1980) of no systematic effects of age, and differs from Walrath and Hallman's (1984) report of the P3 amplitude being consistently smaller in older subjects.

These age-relationship discrepancies further illustrate the need for additional longitudinal studies, as well as a need to clarify developmental effects (Kurtzberg, Vaughan, Chourchesne, Friedman, Harter, & Putnam, 1984) from maturational effects. Such discrepancies also illustrate the difficulty of attempting to interpret ERP results obtained using single-trial research methods.

## ERP Variability over Time

What is clear from this longitudinal study of normal humans is that the neurophysiological characteristics measured by event-related potentials are highly variable, and that test-retest reliability, while acceptable over short time periods (see experiment four) is not stable over long time intervals (see experiment five). This has direct application for ERP research involving two- (or more)- group designs as well as pre-and-post intervention designs. Until the extent of long-term variability of ERPs in both sensory modalities is better clarified for the research populations of interest and under the conditions of interest, it cannot be concluded that the differences observed between two ERP test results administered over a

significant time interval, are necessarily due to inter-group differences or to any applied treatment effect. The basic problem of ERP variability over time remains to be resolved.

These findings do, however, directly apply to the core biological issues in psychopathology: diagnosis, etiology, and clinical change assessment.

Diagnosis. The present investigation has followed the recommendations of Tueting (1984). The two important ERP characteristics of amplitude and latency were assessed individually in both sensory modalities. This contributes to the larger effort among ERP researchers to establish reliable ERP differences among diagnostic groups, which is a prerequisite to using ERPs as a clinical tool. By longitudinally studying normal humans at high latitude, the present investigation serves a baseline, basic research toward a major objective in ERP studies to demonstrate concurrent validity between ERP measures and diagnostic criteria.

Etiology and Clinical Change Assessment. One difficulty with using ERPs to monitor clinical change involves the ERP waveform variability. The majority of ERP experiments use a two-group, single-trial design, assuming that patients and nonpatients are "doing the same thing" (Roemer, & Connelly, 1984, pg. 531). Assessing clinical change requires that the test used have high specificity for the condition and sufficient sensitivity to detect meaningful change

(Pfefferbaum, Ford, & Kraemer, 1990). ERP specificity and sensitivity have not been conclusively demonstrated for clinical conditions such as seasonal mood disorders. The major question of where normal variation ends and where variation due to treatment or pathology begins remains to be answered.

## High Latitude Factors

The present investigation has taken the additional step of investigating the relative contribution of high latitude environmental variables, by means of multivariate techniques (Picton, et al., 1984). Those independent variables measured which clustered in the second principal components factor were the ambient geomagnetic field activity on the day prior to ERP testing, and the photoperiod on the day prior to ERP testing.

Photoperiod. As seen in experiment five, the longitudinally-studied sample of normal humans living at high latitude demonstrated significant monthly variability, in both sensory modalities, for the P3 ERP characteristics of amplitude and latency, over the course of 12 consecutive months. The finding of no hypersomnia associated with photoperiod (experiment six) would tend to validate the participants' self-report of being free of seasonal depression symptoms, at the very least. The principal

components method of factor analysis performed in experiment six, and a comparison of seasonal groupings based on a photoperiod definition (experiment seven) do not support interpreting the variability observed as photoperiodism.

These results contradict the findings which report a seasonal effect in P3 (Deldin, et al., 1989b) and a P3 relationship with amount of available daylight (Deldin, et al., 1989a). The results in experiment seven did not demonstrate a seasonal pattern similar to that observed (Anderson,_et al., 1984) in the longitudinal study of normal EEG's recorded at high latitude. What is needed in future investigations of an ERP relationship with light is for experimental subjects to wear a personal light meter, so that both the duration and intensity of their light exposure may be more accurately quantified.

Geomagnetic Field. This is admittedly a controversial issue even to be included as an independent variable. Human magnetosensitivity is not widely accepted, although researchers addressing the health effects of manmade electromagnetic fields are receiving increased financial support, and recently John Rankine of the IEEE Standards Board (IEEE, 1992) provided testimony before the U. S. Senate in support of "continuing research on bio-effects across the entire frequency spectrum" (pg. 12).

As described, measures of the ambient geomagnetic field, both recent and more distant time components, were

included as naturally-ocurring high latitude environmental variables. As can be seen in experiment six, the descriptors of the ambient geomagnetic field strength became weighted in the second PCA factor. Of the independent variables examined, the geomagnetic field strength was weighted more heavily than photoperiod. From experiment six, it can be seen that the geomagnetic field descriptor (sum 24-hour k) was a positive covariant with the P3 latency of both sensory modalities; the sum 24-hour k positively covaried with auditory P3 amplitude and negatively covaried with visual P3 amplitude. Across both sensory modalities, the geomagnetic field descriptor had a significantly stronger linear correlation with the ERP characteristics than did photoperiod. Larger sums of the 24-hour k were associated with larger auditory amplitudes, smaller visual amplitudes and longer latencies for both modalities.

As can be seen in experiment eight, grouping the longitudinal ERP data using a geomagnetic field strength definition demonstrated that auditory P3 amplitude differed during periods of high geomagnetic field strength compared to periods of low geomagnetic field strength; this difference was significant at an alpha level of 0.10. It was observed that the mean auditory P3 amplitude was higher during high field-strength periods.

However, as discussed previously, this differential effect in one sensory modality may be an artifact of the inherent differences in the two forms of the ERP test.

Measures taken in the recording cubicle at the time of testing did not have a strong relationship with the ERP responses recorded, and thus it is unlikely that the recordings contained stray field artifact. As with photoperiod, what is needed in future investigations of an ERP relationship with geomagnetic field flux, is for experimental subjects to wear a personal magnetometer such that their exposure parameters may be more accurately quantified.

While the results observed in experiment eight may be of potential interest for space exploration and habitation where such fields are absent, the practical significance to humans on Earth is unclear. Human magnetosensitivity has been investigated (Baker, 1988; Becker, 1963; 1990; Kirshvink, 1982; Semm, 1992), however neither the sensory receptor mechanisms nor the physiological consequences have been conclusively identified.

## SUMMARY

The current body of ERP literature has few longitudinal studies, and this work directly addresses that knowledge deficit. Additionally, the results contribute to the discussion of a seasonal pattern in P3 variability which has been suggested to be related to ambient light. The findings also begin the discussion of a possible contribution of geomagnetic field flux to the variability of P3 responses

over time. Significant contribution to ERP knowledge derives from being the longest, most comprehensive, and methodical longitudinal study of normal human ERP variability over time.

Future ERP research has much to accomplish. The physiological generator of these fascinating potentials remains a mystery. The relationship between intracranial generation and scalp-surface recording is not well-understood. The full body of theoretical constructs to be measured by event-related potentials remains to be articulated and verified. Significant issues of reliability of the measuring techniques and methods of analyzing the data are still not satisfactorily resolved. These and many more technological issues must be addressed in future endeavors if event-related potential research is to move from being a still-experimental technique to a sound and useful clinical tool.

REFERENCES:

Aine, C. J., & Harter, M. R. (1984). Hemispheric differences in event-related potentials to stroop stimuli: attention and color-word processing. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vo. 425, pp. 154-156). New York, NY: Annals of the New York Academy of Sciences.

Allport, S. (1986). Explorers of the Black Box--The Search for the Cellular Basis of Memory. New York, NY: W. W. Norton.

American Psychiatric Association, (1987). Diagnostic and statistical manual of mental disorders, (3rd ed., revised). Washington, D.C.: Author.

Anderson, H., Chanbers, M. M. C., Myhre, G., Nicholson, A. N., & Stone, B. M. (1984). Sleep of shiftworkers within the Arctic Circle. Aviation, Space, and Environmental Medicine, November, 1026-1030.

Anderson, V. L., & McLean, R. A. (1974). Design of Experiments, a Realistic Approach. New York, NY: Marcel Dekker, Inc.

Arezzo, J. C., Pickoff, A., & Vaughan, H. G. (1981). Topography and intracranial sources of somatosensory evoked potentials in the monkey. II. Corticol components. Electroencephalography and Clinical Neurophysiology, 51(1) 1-18.

Arthur, D. L., & Starr, A. (1984). Task-relevant late positive component of the auditory event-related potential in monkeys resembles P300 in humans. Science, 223, 186-188.

Associated Press (1991). Sun storms batter Earth. The Fairbanks Daily News-Miner, June 7, 1991, pg. A-7.

Baker, R. R. (1988). Human magnetoreception for navigation. In M. E. O'Conner & R. H. Lovely (Eds.). Electromagnetic Fields and Neurobehavioral Function, New York, NY: Alan R. Liss, Inc.

Bayles, R. L. (1982). Event-related potentials and selective attention. Dissertation Abstracts International, 43, 10-B. (University Microfilms No. GAX83-05895) pg. 3400.

Becker, R. O. (1963). Relationship of geomagnetic environment to human biology. New York State Journal of Medicine, August 1, 2215-2219.

Becker, R. O. (1990). The natural electromagnetic field. In Cross Currents: The perils of electropollution, the promise of electromedicine (pp. 173-185). Los Angeles, CA: Jeremy P. Tarcher, Inc.

Binkley, S. (1979). A timekeeping enzyme in the pineal gland. Scientific American Offprints, No. 1426. San Francisco, CA: W. H. Freeman and Company.

Bird, T. D., & Griep, E. (1981). Pattern reversal visual evoked potentials: Studies in Charcot-Marie-Tooth hereditary neuropathy. Archives of Neurology, 38, 739-741.

Blehar, M. C., & Lewey, A. J. (1990). Seasonal mood disorders: concensus and controversy. Psychopharmacology Bulletin, 26, 465-494.

Borland International (1992). QuatroPro Version 4.0. Scotts Valley, CA: author.

Brigham, J. (1987). Sex and laterality differences in event-related potential responses to affective stimuli. Doctoral dissertaion, Brigham Young University. (University Microfilms No. 8803345).

Brothwell, D. R. (1981). Morphological analysis of human bones. In Digging Up Bones, (3rd ed., pp. 76-115). Ithaca, NY: Cornell University Press.

Brown, F. A. Jr. (1972). The "clocks" timing biological rhythms. American Scientist, 60, 756-766.

Bush, A. M., & Emery, S. (1987). P300 AERP: Objective measurement of attentional fatigue in nurses working eight and twelve hour shifts. Heart & Lung, 16(3):337 (abstract).

Bush, A. M., Geist, C. R., & Emery, S. (1991). Latency of auditory event-related potential P3 correlates with forward digit span in an Alaskan subarctic sample. Perceptual and Motor Skills, 72, 820-822.

Bush, A. M., Geist, C. R., & Emery, S. (1992). Correlation of event-related potential components and academic performance. Presented at the 72nd Annual Convention of the Western Psychological Association, April 30-May 3, 1992, Portland, Oregon.

Buzzelli, D. E. (1993). Policy Forum. The definition of misconduct in science: a view from NSF. Science, 259, 584-585 & 647-648.

Cadwell Laboratories, Inc. (1988). Quantum-84 Operator's Manual, Kennewick, WA: Cadwell Laboratories, Inc..

Churchland, P. S. (1986). Neurophilosophy: Toward a Unified Science of the Mind-Brain. Cambridge, MA: MIT Press.

Conover, W. J. (1980). Practical Nonparametric Statistics, (2nd ed.). New York, NY: John Wiley & Sons.

Courchesne, E. (1978). Changes in P3 waves with event repetition: long-term effects on scalp distribution and amplitude. Electroencephalography and Clinical Neurophysiology, 45, 754-766.

Davis, N. (1989). A sixth sense? Alaska Science Nuggets, (p. 185). Fairbanks, AK: University of Alaska Press.

Deldin, P., Duncan, C. & Miller, G. (1989a). Effects of gender and daylight exposure on P300. Proceedings of the Annual Meeting of the Society for Psychphysiological Research. New Orleans, Louisiana.

Deldin, P., Duncan, C., & Miller, G. (1989b). Evidence for seasonal effects on P300. Proceedings of the EPIC IX: 9th International Conference on Event-Related Potentials of the Brain. Noordwijk, Netherlands.

Dixon, W. J. (Chief Editor). (1990). BMDP Statistical Software Manual. Berkeley, CA: University of California Press.

Donchin, M. (1984). Intimations of mentality. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, p. 758), New York, NY: The New York Academy of Sciences.

Drake, M. E. (1990). Clinical utility of event-related potentials in neurology and psychiatry. Seminars in Neurology, 10(2), 196-203.

Duncan, C. C., & Rosenthal, N. E. (1986). Effects of phototherapy on brain potentials in patients with seasonal affective disorder: a pilot study. Society for Psychological Research, 26th Annual Meeting, Oct. 16-19, 1986, Montreal, Canada.

Ehrlich, E., Flexner, S. G., Carruth, G., & Hawkins, J. M. (Eds.). (1980). Oxford American Dictionary. New York, NY: Oxford University Press.

Fowler, B., Kelso, B., Landolt, J., & Porlier, G. (1988). The effects of nitrous oxide on P300 and reaction time. Electroencephalography and Clinical Neurophysiology, 69, 171-178.

Friedman, H., Becker, R. O., & Bachman, C. H. (1963). Geomagnetic parameters and psychiatric hospital admissions. Nature, 200(4907), 626-628.

Friedman, H., Becker, R. O., & Bachman, C. H. (1965). Psychiatric ward behaviour and geophysical parameters. Nature, 205(4976), 1050-1052.

Friel, J. P. (Ed.) (1974). Dorland's Illustrated Medical Dictionary, (25th ed.). Philadelphia, PA: W. B. Saunders.

Gibbons, J. H. (director). (1991). U.S. Congress, Office of Technology Assessment. Biological Rhythms: Implications for the Worker (OTA-BA-463). Washington, DC: U.S. Government Printing Office.

Goodin, D. S. (1990). Clinical utility of long latency 'cognitive' event-related potentials (P3): the pros. Electroencephalography and Clinical Neurophysiology, 76, 2-5.

Goodin, D. S., Squires, K. C., Henderson, B. H., & Starr, A. (1978). Age-related variations in evoked potentials to auditory stimuli in normal human subjects. Electroencephalography and Clinican Neurophysiology, 44, 447-458.

Groth-Marnat, G. (1990). Handbook of Psychological Assessment, (2nd ed.). New York, NY: John Wiley & Sons.

Halgren, E., Squires, N. K., Wilson, C. L., Rohrbauth, J. W., Babb, T. L., & Crandall, P. H. (1980). Endogenous potentials generated in the human hippocampal formation and amygdala by infrequent events. Science, 210, 803-805.

Halliday, M. (1984). Tales of untold riches. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-related potentials, (Vol. 425, p. 764). New York, NY: Annals of the New York Academy of Sciences.

Halliday, R., Callaway, E., & Lynch, M. (1984). Age, stimulant drug and practice effects on P3 latency and concurrent reaction time. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-related potentials, (Vol. 425, pp. 357-362). New York, NY: Annals of the New York Academy of Sciences.

Harrison, J. B., Buchwald, J. S., Kaga, K., Woolf, N. J., & Butcher, L. L. (1988). 'Cat p330' disappears after septal lesions. Electroencephalography and Clinical Neurophysiology, 69(1), 55-64.

Harter, M. R., Aine, C. & Schroeder, C. (1984). Hemispheric differences in event-related potential measures of selective attention. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-related potentials, (Vol. 425, pp. 210-212). New York, NY: Annals of the New York Academy of Sciences.

Hellekson, C. (1989). Phenomenology of seasonal affective disorder: an Alaskan perspective. In N. E. Rosenthal & M. C. Blehar (Eds.). Seasonal Affective Disorders and Phototherapy, (pp. 33-44). New York, NY: The Guilford Press.

Hellekson, C. & Rosenthal, N. (1987). New light on seasonal mood changes. Mental Health Letter, 3(10), 1-6.

Hillyard, S. & Kutas, M. (1983). Electrophysiology of cognitive processing. Annual Reviews in Psychology, 34, 33-61.

Hoenig, S. A. (1980). How to build and use electronic devices without frustration, panic, mountains of money, or an engineering degree (2nd ed.). Boston, MA: Little, Brown and Co..

Hubel, D. H. (1988). Eye, Brain, and Vision. New York, NY: Scientific American Library.

IEEE. (1992). IEEE Supports Standard at Senate Hearing. IEEE Standards Bearer, 6(3):12. Piscatawy, NJ: The Institute of Electrical and Electronics Engineers, Inc..

IEEE (1989). Biological effects of power frequency electric and magnetic fields: IEEE U.S. Activities Board/Entity Position Statement, March 9, 1989. IEEE Engineering in Medicine and Biology Magazine, September, 46-47.

Interagency Arctic Research Policy Committee. (1987). United States Arctic Research Plan. Washington, DC: U.S. Government Printing Office.

Johnson, L. C. (1982). Sleep deprivation and performance. In W. B. Webb (Ed.). Biological Rhythms, Sleep, and Performance (pp. 111-138). New York, NY: John Wiley & Sons.

Johnson, Jr., R. (1986). A triarchic model of P300 amplitude. Psychophysiology, 23, 367-384.

Johnson, Jr., R. (1988). The amplitude of the P300 component of the event-related potential: review and synthesis. In P. J. Ackles, R. J. Jennins, & M. G. H. Coles (Eds.). Advances in Psychophysiology, 3, 69-135.

Karrer, R. (1984). Tales of untold riches. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, pp. 761-762). New York, NY: The New York Academy of Sciences.

Karrer, R., Cohen, J., & Tueting, P. (Eds.) (1984). Brain and Information: Event-Related Potentials, (Vol. 425). New York, NY: The New York Academy of Sciences.

Kaskey, B. (1984). Introduction to ERPs and Psychopathology II. Biological Issues In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, p. 523). New York, NY: The New York Academy of Sciences.

Kirshvink, J. L. (1982). Biogenic ferrimagnetism: a new biomagnetism. In S. J. Williamson, G.-L. Romani, L. Kaufman, & I. Modena (Eds.). Biomagnetism: An Interdisciplinary Approach, p. 501-535. New York, NY: Plenum Press.

Kohlman, B., & Denlinger, C. G. (1988). Calculus For the Management, Life, and Social Sciences, (2nd ed.). New York, NY: Harcourt Brace Jovanovich, Publishers.

Kolb, B., & Whishaw, I. Q. (1990). Fundamentals of Human Neuropsychology, (3rd ed.). New York, NY: W. H. Freeman & Co..

Koppell, B. S., Roth, W. T., & Tinklenberg, J. R. (1978). Time course effects of marijuana and ethanol on event-related potentials. Psychopharmacology, 56, 15-20.

Kurtzberg, D., Vaughan, J. G., Courchesne, E., Friedman, D., Harter, R., & Putnam, L. E. (1984). Developmental aspects of event-related potentials. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, pp. 300-319). New York, NY: The New York Academy of Sciences.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. Science, 197, 792-795.

Lawson, E. A., Barret, G., Kriss, A., & Halliday, A. M.. (1984). P300 and VEPs in Huntington's Chorea. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol 425. pp. 592-598). New York, NY: The New York Academy of Sciences.

Lescher, R. D. (1981). P3 and age-related changes in cognitive function. Dissertation Abstracts International, 42, 07-B, (University Microfilms No. GAX81-27852, p. 3025).

Lewy, A., Sack, R. I., & Singer, C. M. (1984). Assessment and treatment of chronobiologic disorders using plasma melatonin levels and bright light exposure: the clock-gate model and phase response curve. Psychopharmacology Bulletin, 20, 565-565.

Lewy, A., Sack, R. I., & Singer, C. M. (1985),. Immediate and delayed effects of bright light on human melatonin production: shifting "dawn" and "dusk" shifts the dim light melatonin onset (DLMO). Annals of the New York Academy of Sciences, 453, 252-259.

Loveless, N. (1983). Event-related potentials and human performance. In Physiological Correlates of Human Behavior, London: Academic Press.

Martin, L., Barajs, J. J., Fernandez, R., & Torres, E. (1988). Auditory event-related potentials in well-characterized groups of children. Electroencephalography and Clinical Neurophysiology, 71, 375-381.

Mayaud, P. N. (1980). Derivation, meaning and use of geomagnetic indices (Geophysical Monograph 22). Washington, D. C.: American Geophysical Union.

McCarthy, G., & Donchin, E. (1981). A metric for thought: a comparison of P300 latency and reaction time. Science, 211, 77-80.

Miller, D. R. (1985). Some electrophysiological correlates of affect and memory. Dissertation Abstracts International, 46, 11-B, (University Microfilms No. GAX86-01211, p. 4060).

Moore-Ede, M. C., Sulzman, F. M., & Fuller, C. A. (1982). The Clocks That Time Use, Physiology of the Circadian Timing System. Cambridge, MA: Harvard University Press.

Nassman, V. (1988). Parietal P3 amplitude as an indicator of category discrimination. Dissertation Abstracts International, 49, 11-B, (University Microfilms No. GAX89-02677, p. 5057).

Netter, J., Wasserman, W., & Kutner, M. H. (1985). Applied Linear Statistical Models: Regression, Analysis of Variance and Experimental Desings, (2nd ed.). Homewood, Illinois: Richard D. Irwin, Inc.

Nunez, P. L. (1981). Electric Fields of the Brain. New York, NY: Oxford University Press.

Petsche, H., Pockberger, H., & Rappelsberger, P. (1984). On the search for the sources of the electroencephalogram. Neuroscience, 11(1), 1-27.

Pfefferbaum, A. (1984). Tales of untold riches. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, pp. 762-763). New York, NY: The New York Academy of Sciences.

Pfefferbaum, A., Ford, J. M., & Kraemer, H. C. (1990). Clinical utility of long latency 'cognitive' event-related potentials (P3): the cons. Electroencephalography and Clinical Neurophysiology, 76, 6-12.

Pfefferbaum, A., Horvath, T. B., Roth, W. T., & Kopell, B. S (1979). Event-related potential changes in chronic alcoholics. Electroencephalography and Clinical Neurophysiology, 47, 637-647.

Pfefferbaum, A., Ford, J. J., Roth, W. T., & Koppell, B. S. (1980). Age-related changes in auditory event-related potentials. Electroencephalography and Clinical Neurophysiology, 49, 266-276.

Picton, T. (1984). Event-related potentials: whence? where? whither? In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials (Vol. 425, pp.753-766). New York, NY: The New York Academy of Sciences.

Picton, T. W., Hink, R. F., Perez-Abalo, M., Dean, R., Wiens, L., & Wiens, A. S. (1984). Evoked potentials: How now? In Journal of Electrophysiological Technology, 10, 177-221.

Picton, T., & Scherg, M. (1991). Auditory evoked potentials: recent research (1986-1990). In C. Barber, & M. J. Taylor (Eds.). Evoked Potentials Review, (No. 4, pp. 15-28). Nottingham: IEPS Publications.

Picton, T. W., Stuss, D. T., Champagne, S. C., & Nelson, R. F. (1984). The effects of age on human event-related potentials. Psychophysiology, 21(3): 312-325.

Pineda, J. A., Foote, S. L., Neville, H. J., & Holmes, T. C. (1988). Endogenous event-related potentials in monkey: the role of task relevance, stimulus probability, and behavioral response. Electroencephalography and Clinical Neurophysiology, 70(2), 155-171.

Polich, J., Howard, L., & Starr, A. (1983). P300 latency correlates with digit span. Psychophysiology, 20, 665-669.

Renault, B., Ragot, R., Lesevre, N., & Remond, A. (1982). Onset and offset of brain events as indices of mental chronometry. Science, 215, 1413-1415.

Rey, L. (1985). The Arctic Challenge. In R. Fortuine (Ed.). Circumpolar Health 84: Proceedings of the Sixth International Symposium on Circumpolar Health, Seattle, WA: University of Washington Press.

Richer, F., Johnson, R. A., & Beatty, J. (1983). Sources of late components of the brain magnetic response. Society of Neuroscience Abstracts, 9, 656.

Rockstroh, B., Elbert, T., Canavan, A., Lutzenberger, W., & Birbaumer, N. (1989). Slow Cortical Potentials and Behaviour, (2nd ed.). Baltimore, MD: Urban & Schwarzenberg.

Roemer, R., & Connolly, J. (1984). Diagnosis. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425 pp. 525-528). New York, NY: The New York Academy of Sciences.

Rosenberg, C., Nudleman, K., & Starr, A. (1985). Cognitive evoked potentials (P300) in early Huntington's disease. Archives of Neurology, 42, 984-987.

Rosenthal, N. E., Sack, D. A., Gillin, J. C., Lewy, A. J., Goodwin, F. K., Mueller, P. S., Newson, D. A, & Wehr, T. A. (1984). Seasonal affective disorder: a description of the syndrome and preliminary findings with light therapy. Archives of General Psychiatry, 41, 72-80.

Rosenthal, N. E., & Wehr, T. A. (1987). Seasonal affective disorders. Psychiatric Annals, 17, 670-674.

Sarnat, H. B., & Netsky, M. B. (1981). Evolution of the Nervous System, (2nd ed.). New York, NY: Oxford University Press.

SAS/STAT User's Guide, Version 6.0, (1989) (4th ed., No. 2). Cary, NC: SAS Institute, Inc.

Schmidt, J. A., & Pilkington, T. C. (1991). The volume conductor effects of anisotropic muscle on body surface potentials using an eccentric spheres model. IEEE Transactions on Biomedical Engineering, 38(3), 300-304.

Schoenberg, C. E. (1987). Event-related potential indices of memory changes in aging. Dissertation Abstracts International, 48, 08-B, (University Microfilms No. GAX87-23600, p. 2494).

Semm, P. (1992). Pineal function in mammals and birds is altered by earth-strength magnetic fields. In M. C. Moore-Ede, S. S. Campbell, & R. J. Reiter (Eds.) Electromagnetic Fields and Circadian Rhythmicity (pp.53-62). Boston, MA: Birkhauser Boston.

Semm, P., Schneider, T., & Vollrath, L. (1980). Effects of an earth-strength magnetic field on electrical activity of pineal cells. Nature, 288, 607-608.

Smith, K. J. (1986). Analytical Trigonometry. In Precalculus Mathematics: A Functional Approach, (3rd ed.) Monterey, CA: Brooks/Cole Publishing Co..

Squires, N. K., Donchin, E., Squires, K. C., & Grossberg, S. (1977). Bisensory stimulation: inferring decision-related processes from the P300 component. Journal of Experimental Psychology: Human Perception and Performance, 3(2), 299-315.

Stapleton, J. M. (1985). Depth and scalp endogenous potentials evoked in simple cognitive tasks. (Doctoral dissertation, University of California Los Angeles). Dissertation Abstracts International, 46, 04-B, (University Microfilms International, GAX85-13163, p. 1372.).

Steinschneider, M., Arezzo, J., & Vaughan, H. G. (1980). Phase-locked cortical responses to a human speech sound and low-frequency tones in the monkey. Brain Research, 198, 75-84.

Stok, C. J., & Wognum, P. M. (1988). A noniterative approximate solution method for volume conductor problems based on the finite difference method. IEEE Transactions on Biomedical Engineering, 35(1), 31-35.

Stone, R. (Ed.). (1993). MSU coughs up partial mea culpa. Science, 259, pg. 1111.

Sun storms batter earth. (June 7, 1991). Fairbanks Daily News-Miner, p. 3.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked potential correlates of stimulus uncertainty. Science, 150, 1187-1188.

Sutton, S., & Ruchkin, D. S. (1984). The late positive complex: advances and new problems. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, pp.1-23). New York, NY: The New York Academy of Sciences.

Syndulko, K., Cohen, S. N., Tourtellotte, W. W., & Potvin, A. R. (1982). Endogenous event-related potentials: prospective applications in neuropsychology and behavioral neurology. Behavioral Neurology, 124-140.

Tueting, P. (1984). Introduction to ERPs and psychopathalogy II. Biological issues. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, p. 523). New York, NY: The New York Academy of Sciences.

Vaughan,, Jr., H. G., & Ritter, W. (1970). The sources of auditory evoked responses recorded from the human scalp. Electroencephalography and Clinical Neurophysiology, 28, 360-367.

Walrath, L. C., & Hallman, L. E. (1984). Habituation of the event-related potential in elderly and young subjects. In R. Karrer, J. Cohen, & P. Tueting (Eds.). Brain and Information: Event-Related Potentials, (Vol. 425, pp. 391-397). New York, NY: The New York Academy of Sciences.

Wehr, T. A. (1991). The durations of human melatonin secretion and sleep respond to changes in daylength (photoperiod). Journal of Clinical Endocrinology and Metabolism, 73(6), 1276-1280.

Welker, H. A., Semm, P., Willig, R. P., Commentz, J. C., Wiltschko, W., & Vollrath, L. (1983). Effects of an artifical magnetic field on the serotonin N-acetyl transferase activity and melatonin content of the rat pineal gland. Experimental Brain Research, 50, 426-432.

While, S. C., Parker, E. S., & Noble, E. P. (1988). An atypical neurocognitive profile in alcoholic fathers and their sons. Journal of Studies on Alcoholism, 49(3): 240-244.

WHO (1987). Environmental Health Criteria 69, Magnetic Fields. Geneva, Switzerland: World Health Organization.

Wilkinson, L. (1990). SYSTAT: The System for Statistics. Evanston, IL: SYSTAT, Inc.

Willerman, L. Schultz, R., Rutledge, M. N., & Bigler, E. D. (1991). In vivo brain size and intelligence. Intelligence, 15, 223-228.

Winer, B. J. (1971). Statistical Principles in Experimental Design, (2nd ed.). New York, NY: McGraw-Hill Book Company.

WNET-TV (Producer) (1990). The Mind (VHS film, The Annenberg/CPB Collection). Santa Barbara, CA: Intellimation.

Wood, C. C., Allison, T., Goff, W. R., Williamson, P. D., & Spencer, D. D. (1980). On the neural origin of P300 in man. Progress in Brain Research, 54, 51-56.

Yiannikas, C., Walsh, J. C., & McLeaod, J. G. (1983). Visual evoked potentials in the detection of subclinical optic toxic effects secondary to ethambutol. Archives of Neurology, 40, 645-648.

Zamora, E. A., Bush, A., & Geist, C. R. (1992). Effects of a moderate dose of caffeine on event-related brain potentials. Presented at the September 1992 Arctic Science Conference, Valdez, Alaska, American Association for the Advancement of Science.

Zar, J. H. (1984). Biostatistical Analysis, (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc.

# APPENDICES

Appendix A: Retrospective Study of ERPs During a Geomagnetic Storm

Appendix B: Graphical Presentation of the Variability of the Event-Related Potential Components Not Formally Analyzed.

Figure A-1. Daily equivalent amplitude deviations from background (Ak) during solar-flare induced goemagnetic storm (June 1991) and for two months pre-and-post-storm activity. Human event-related potentials were recorded during the period of the June 1991 storm, and compared with age-and-sex-matched controls recorded prior to the storm.

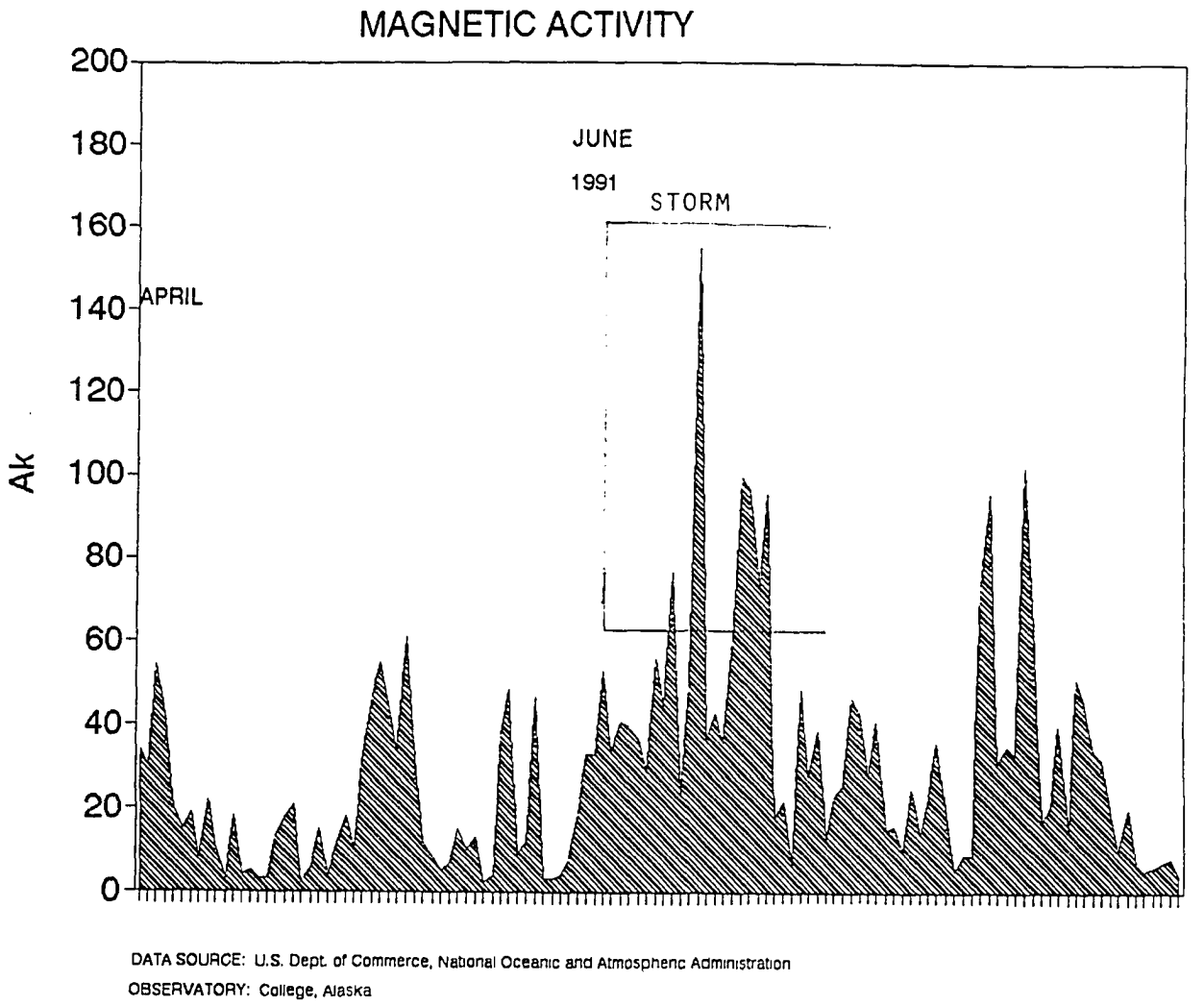


Figure A-2. ERP P3 amplitude of the storm group compared to the control group.

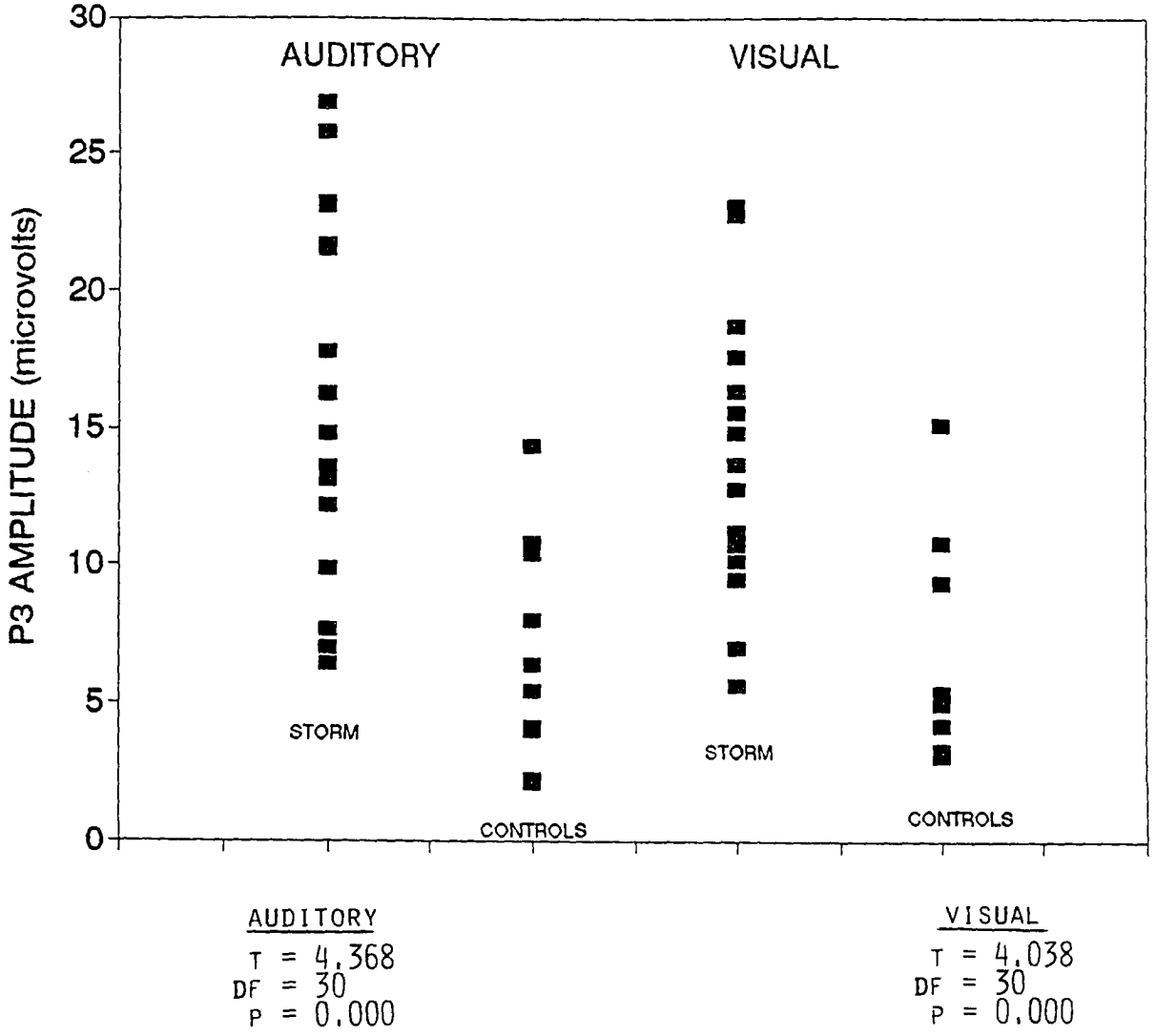


Figure A-3. ERP P3 latency of the storm group compared to the control group.

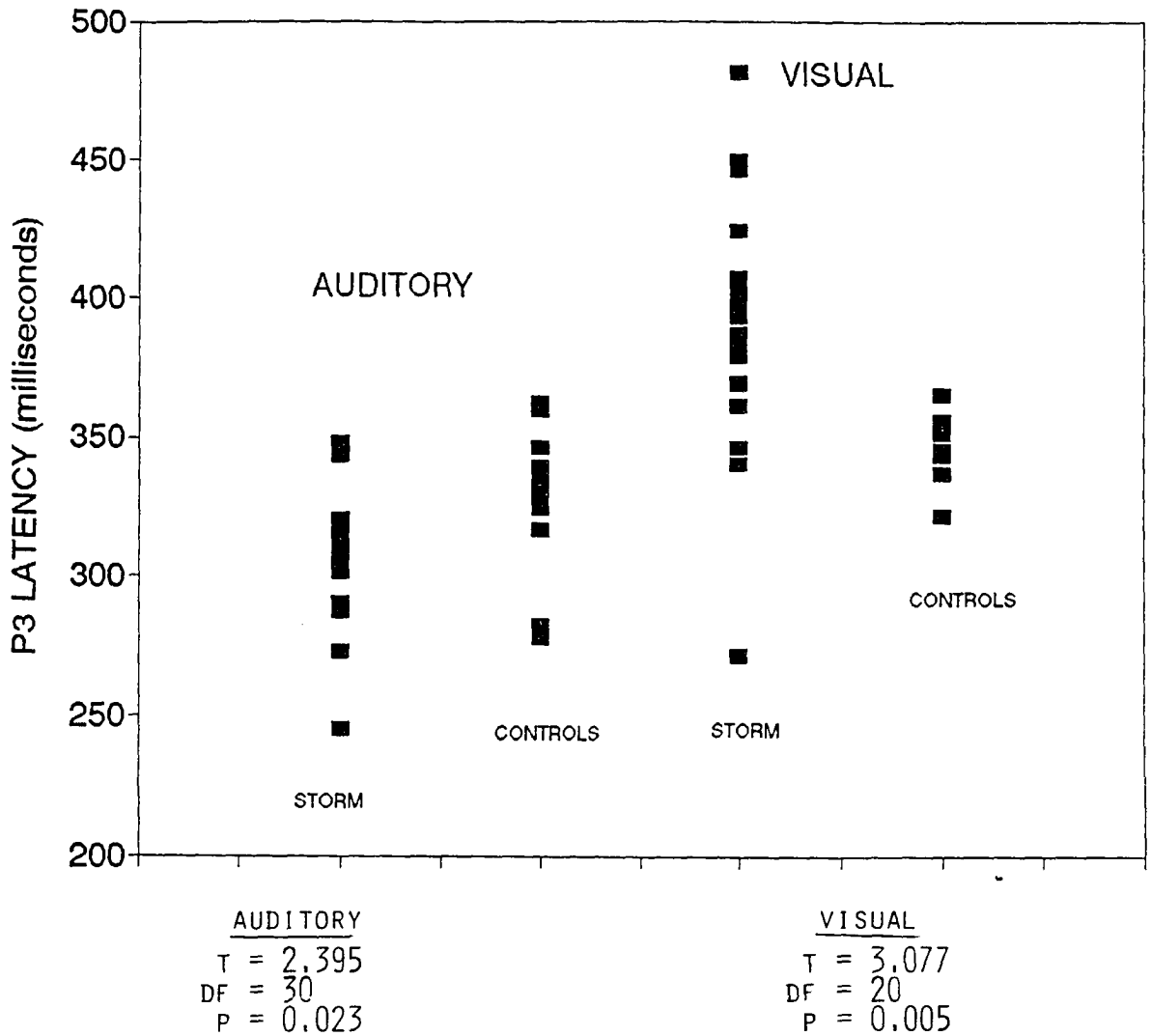
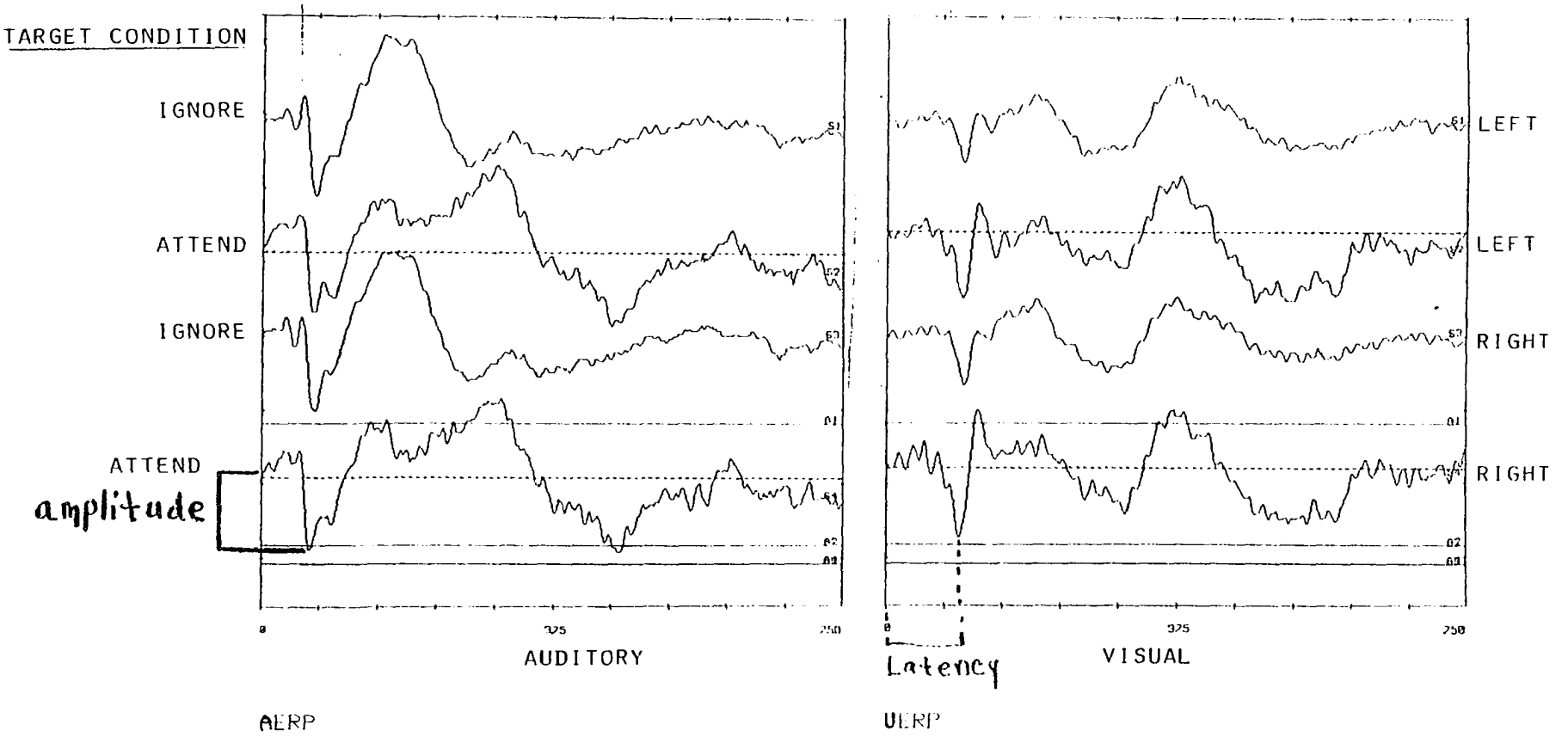


Figure B-1. N1 portion of ERPs.




N1

Figure B-2. Variability of the attended auditory N1 amplitude over 12 months.

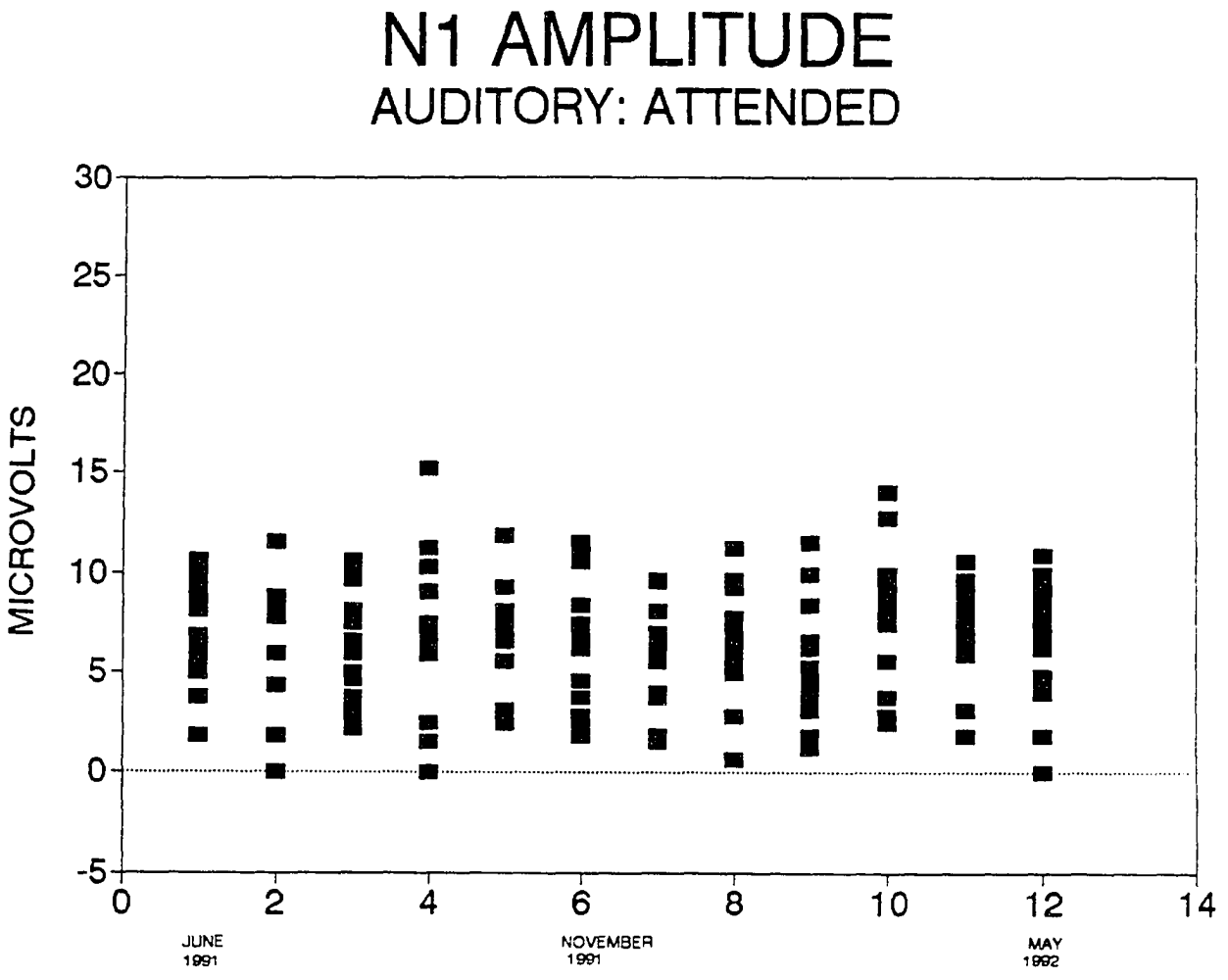


Figure B-3. Variability of the ignored auditory N1 amplitude over 12 months.

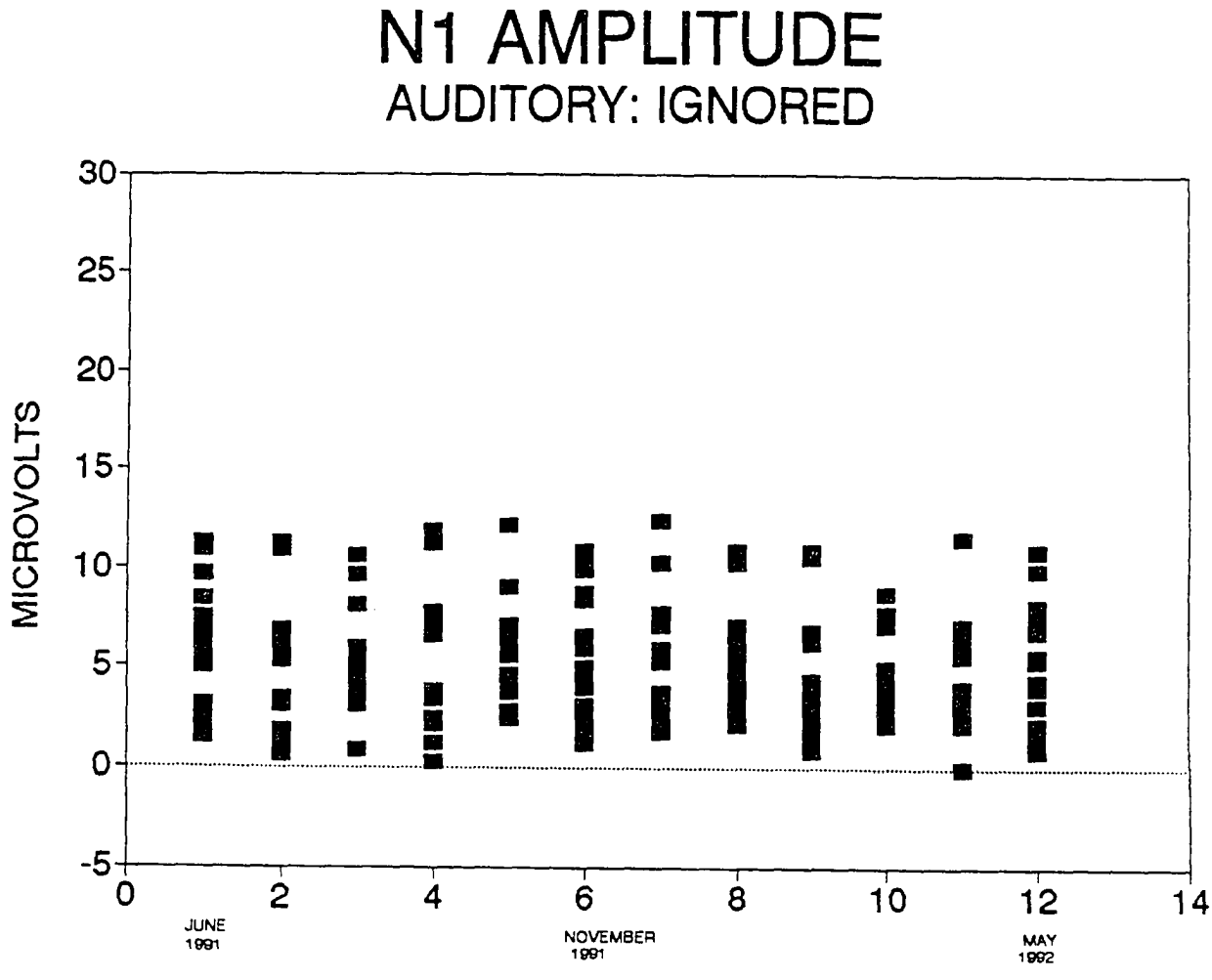


Figure B-4. Variability of the attended visual N1 amplitude over 12 months.

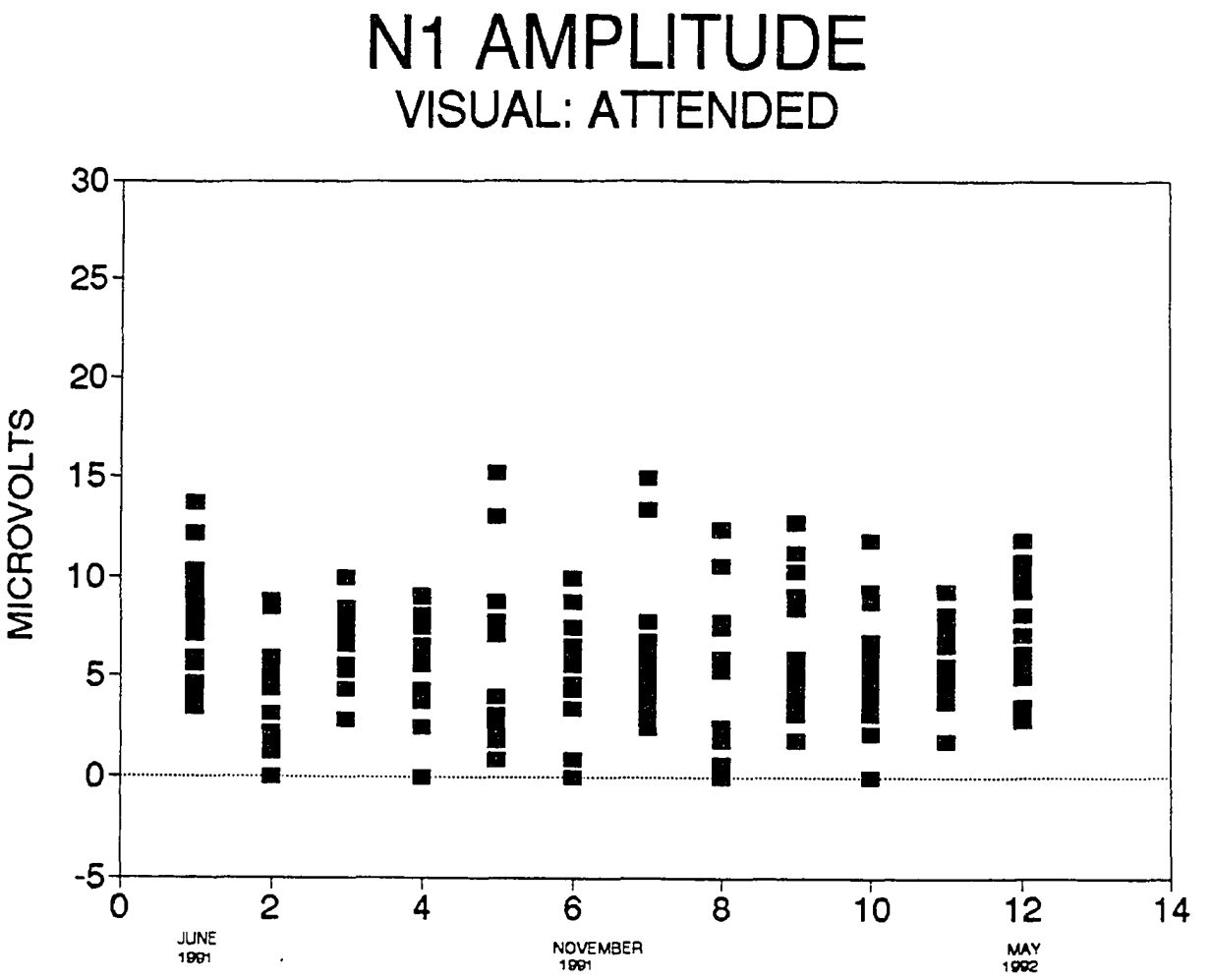


Figure B-5. Variability of the ignored visual N1 amplitude over 12 months.

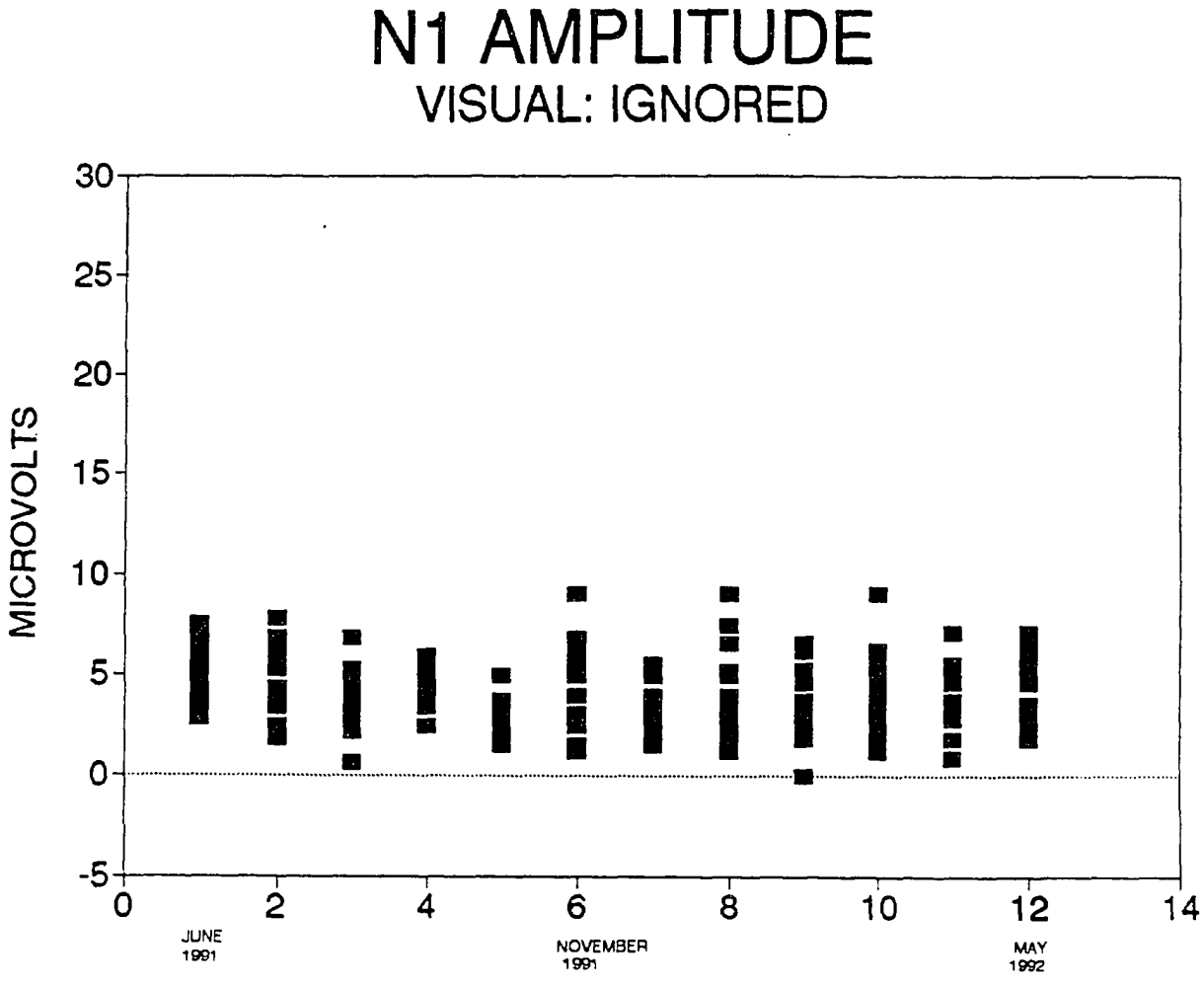


Figure B-6. Variability of the attended auditory N1 latency over 12 months.

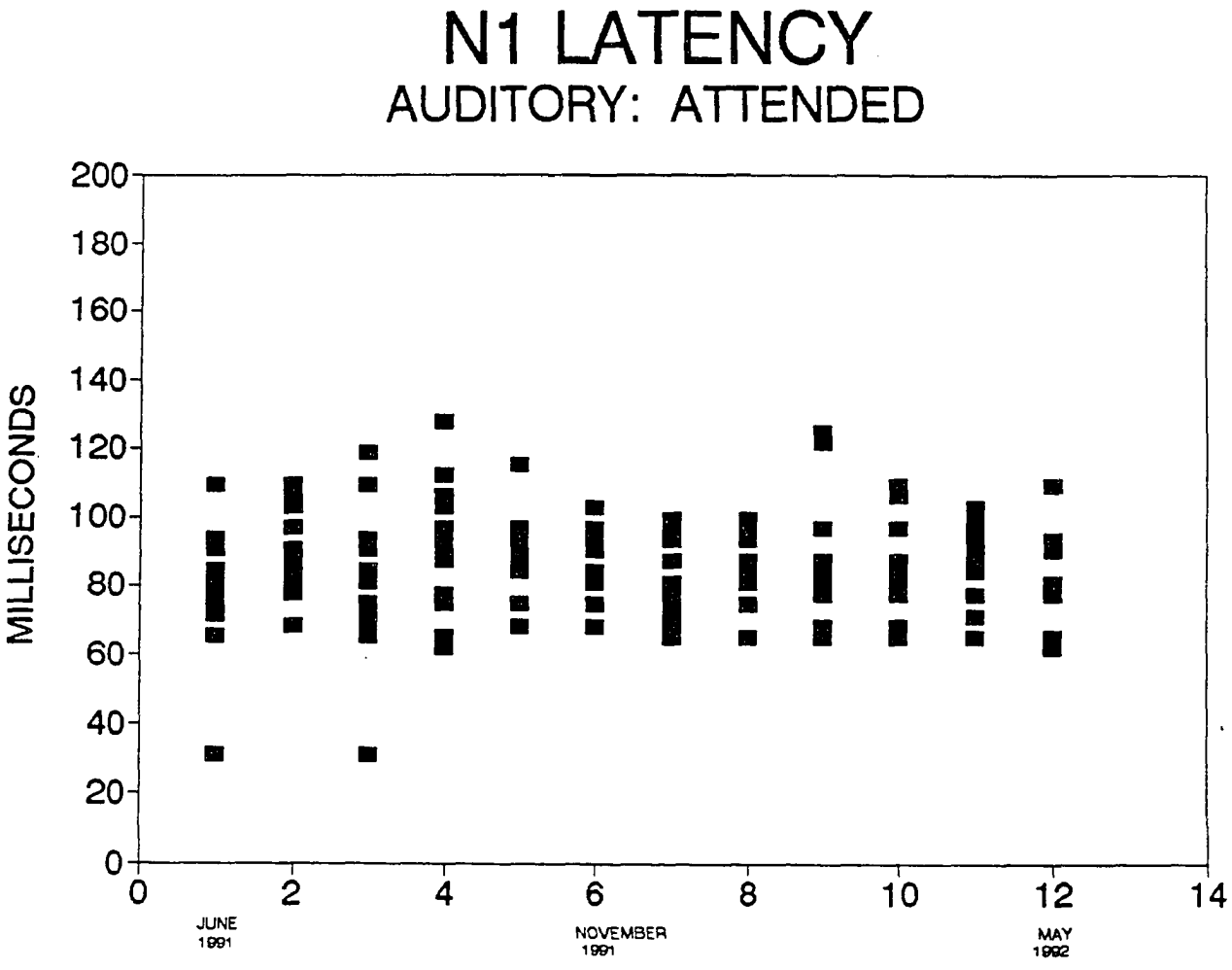


Figure B-7. Variability of the ignored auditory N1 latency over 12 months.

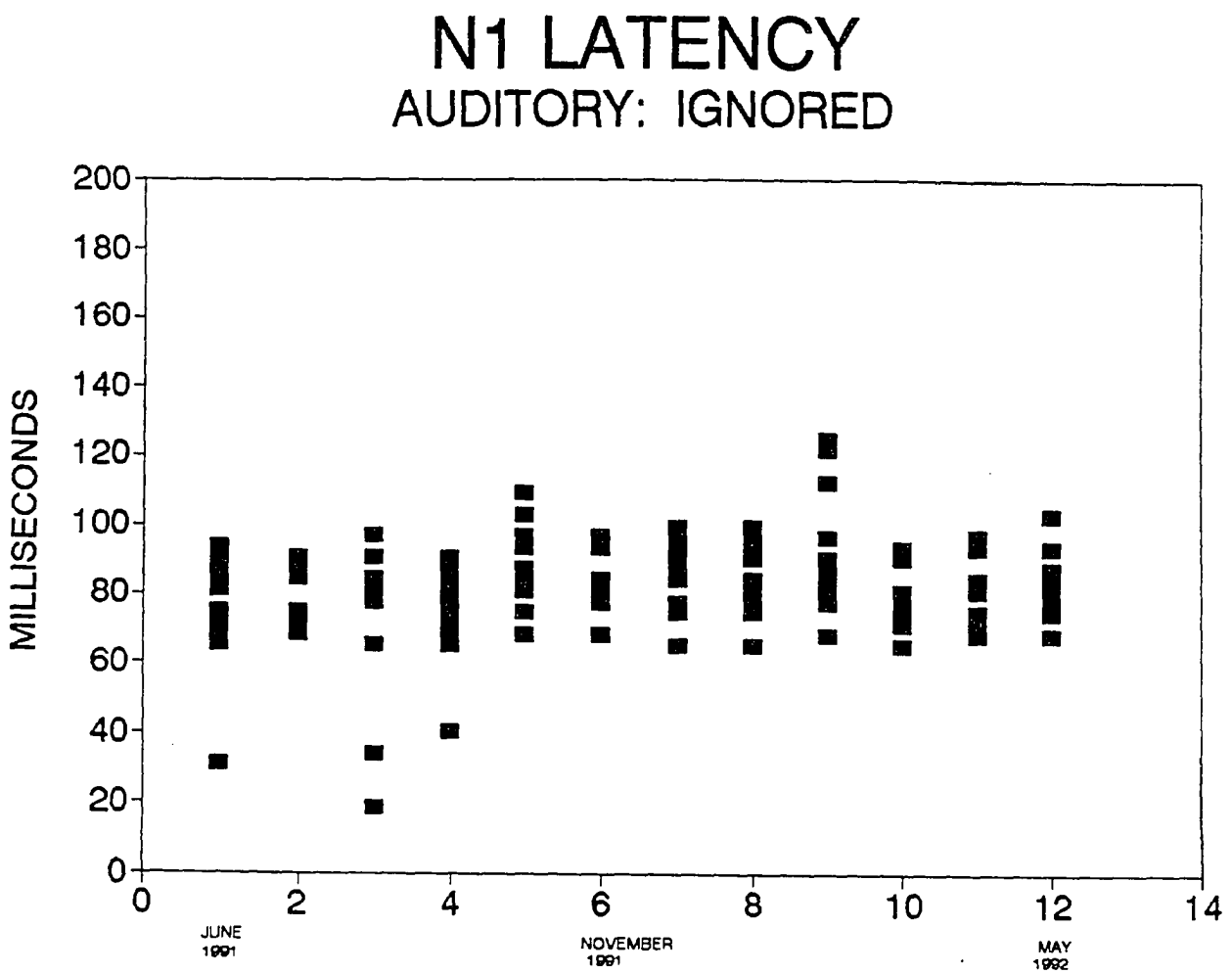


Figure B-8. Variability of the attended visual N1 latency over 12 months.

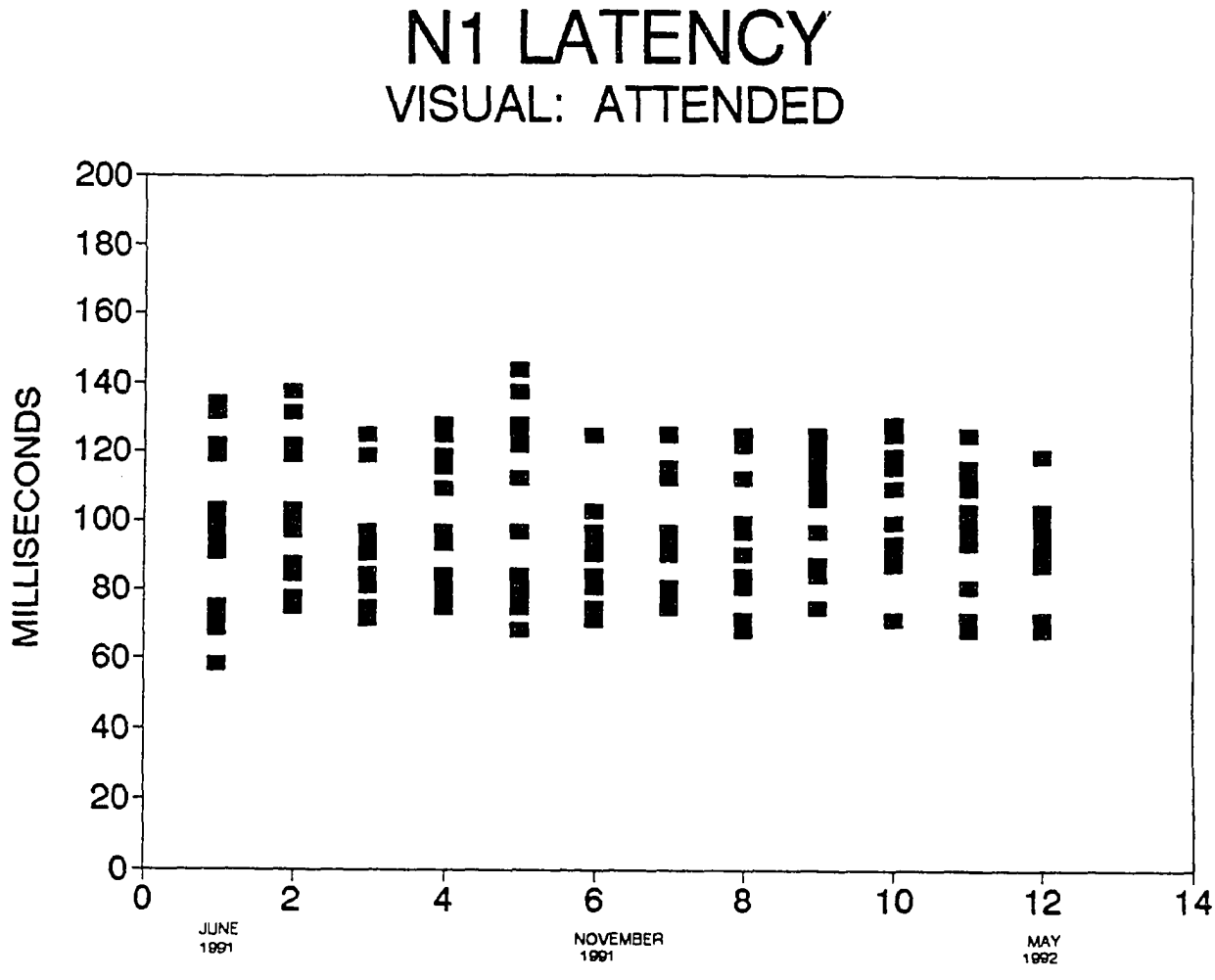


Figure B-9. Variability of the ignored visual N1 latency over 12 months.

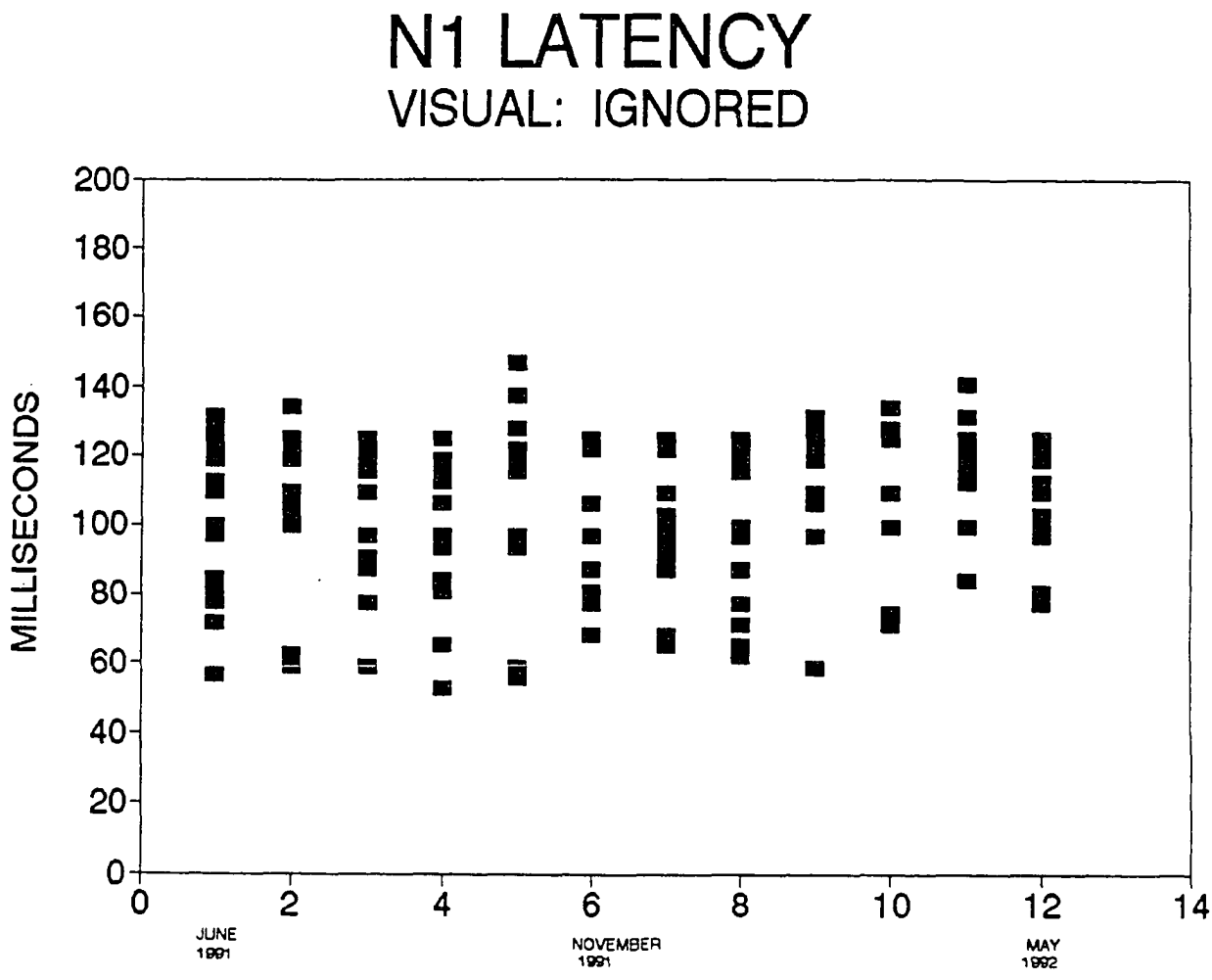
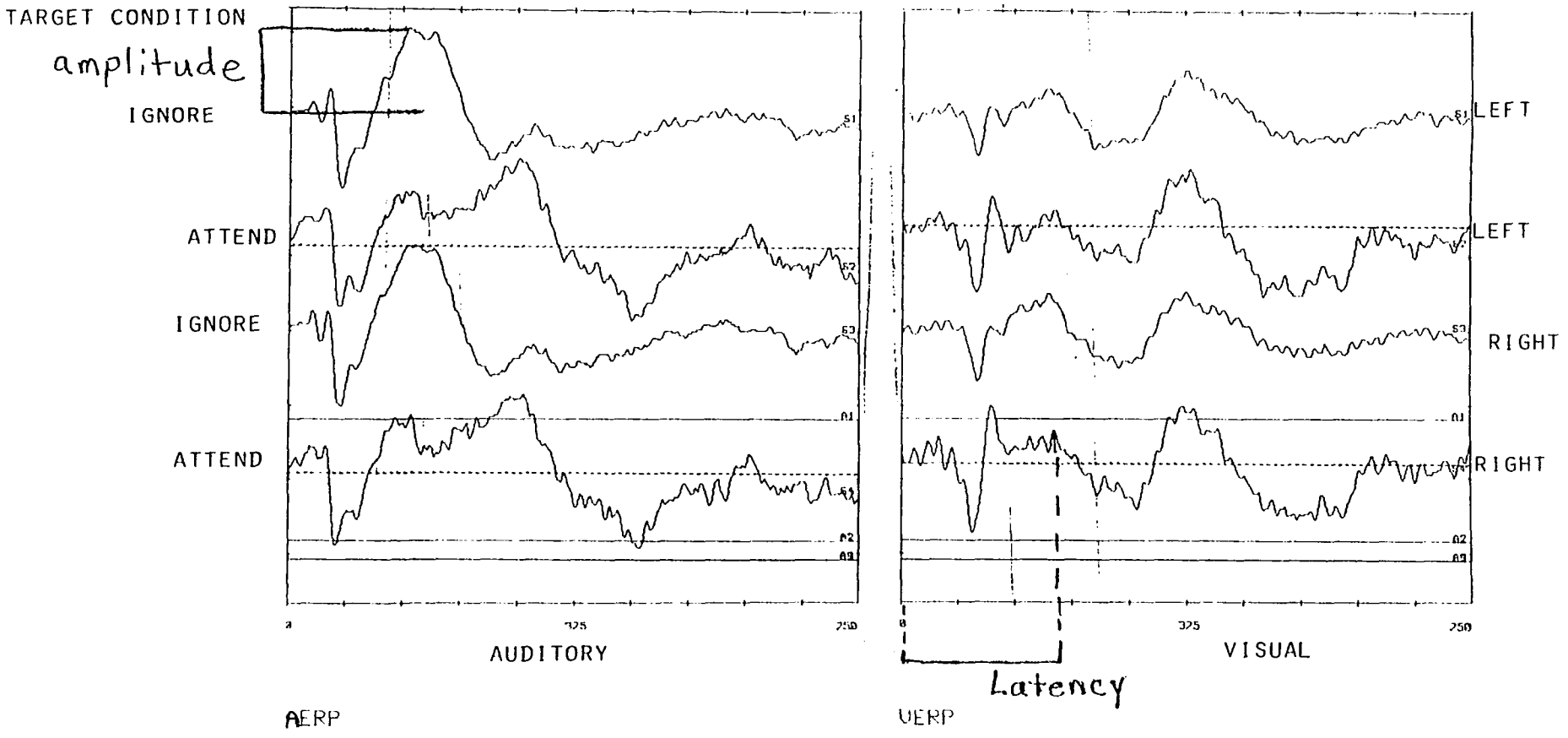


Figure B-10. P2 portion of the ERPs.




P 2

Figure B-11. Variability of the attended auditory P2 amplitude over 12 months.

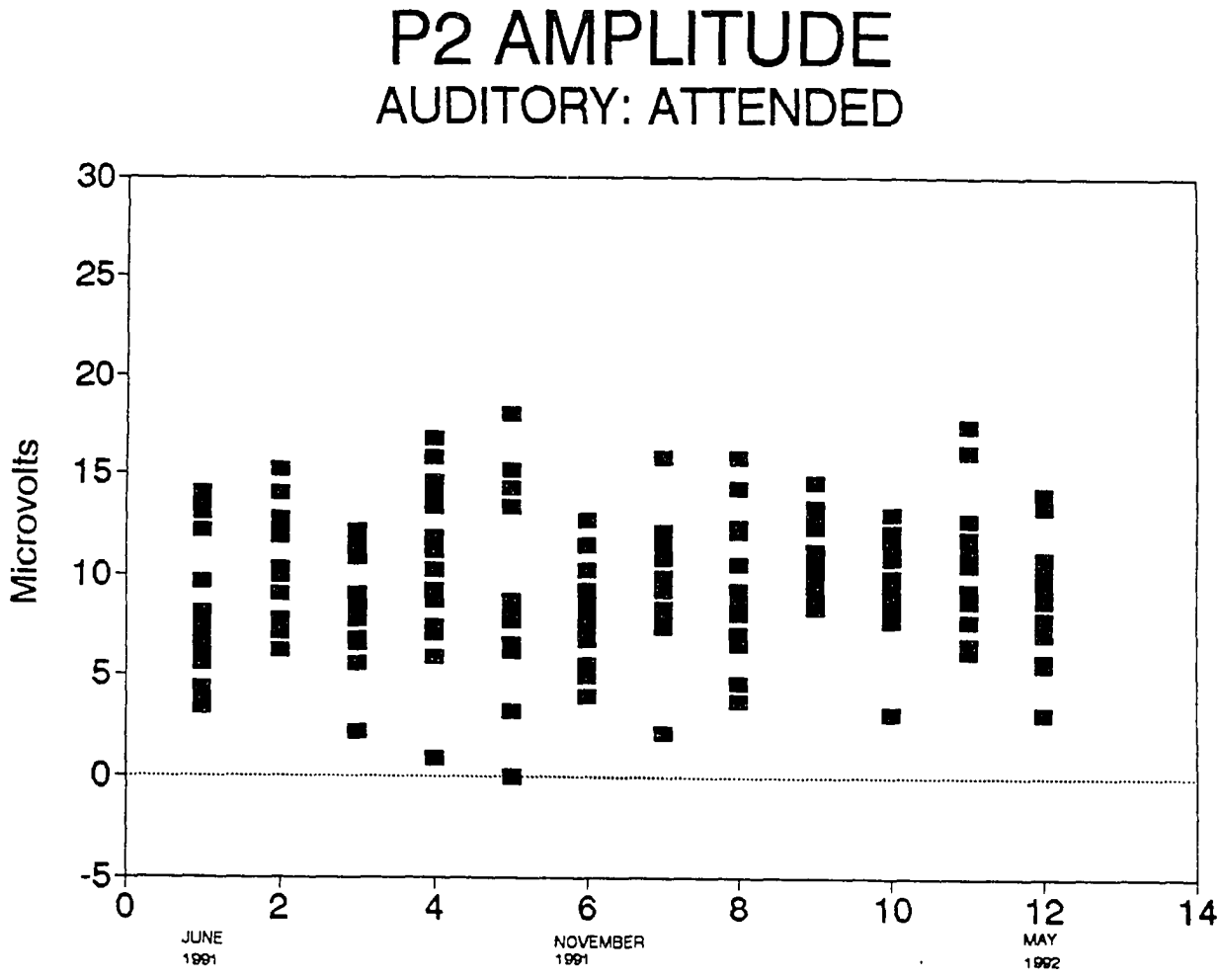


Figure B-12. Variability of the ignored auditory P2 amplitude over 12 months.

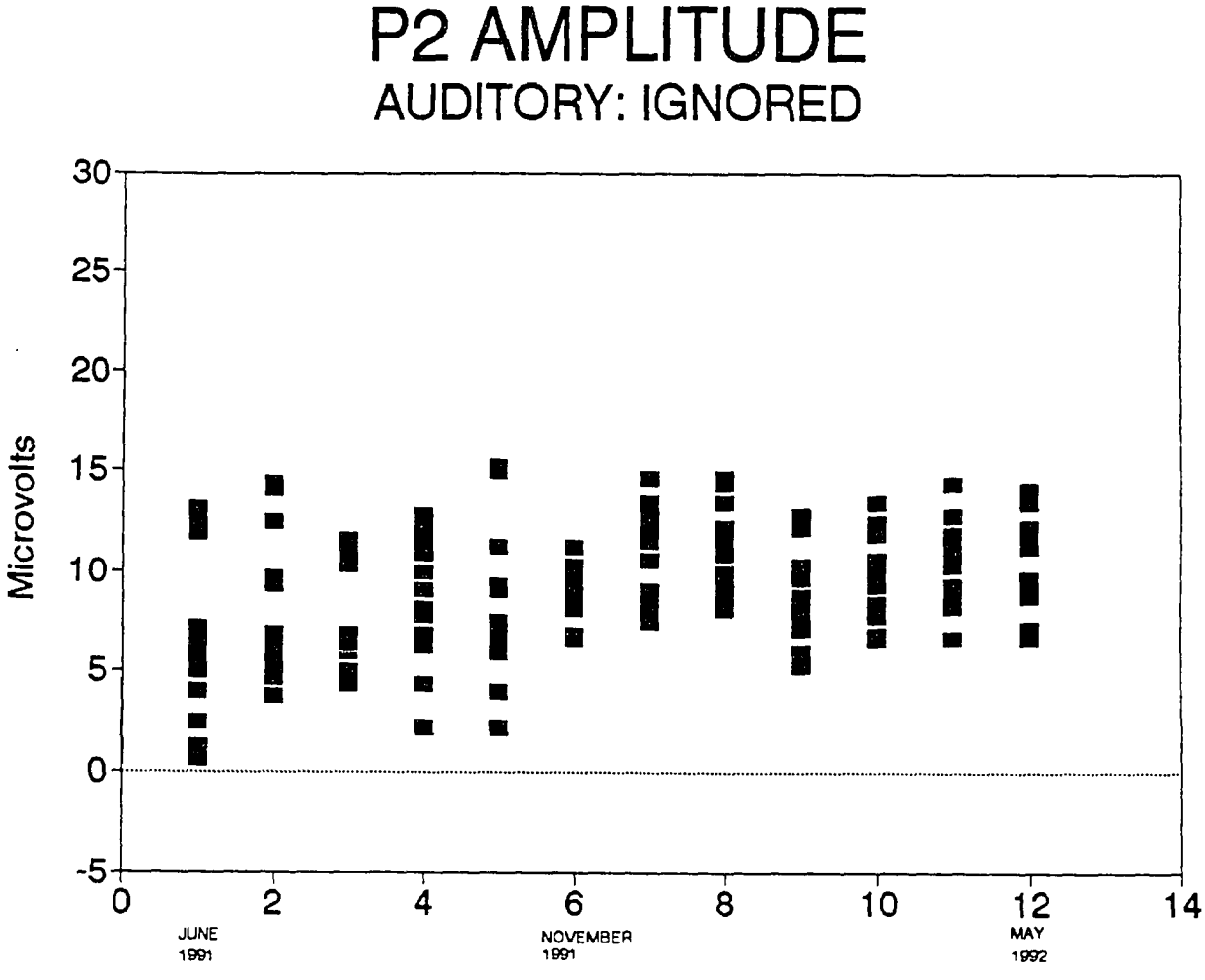


Figure B-13. Variability of the attended visual P2 amplitude over 12 months.

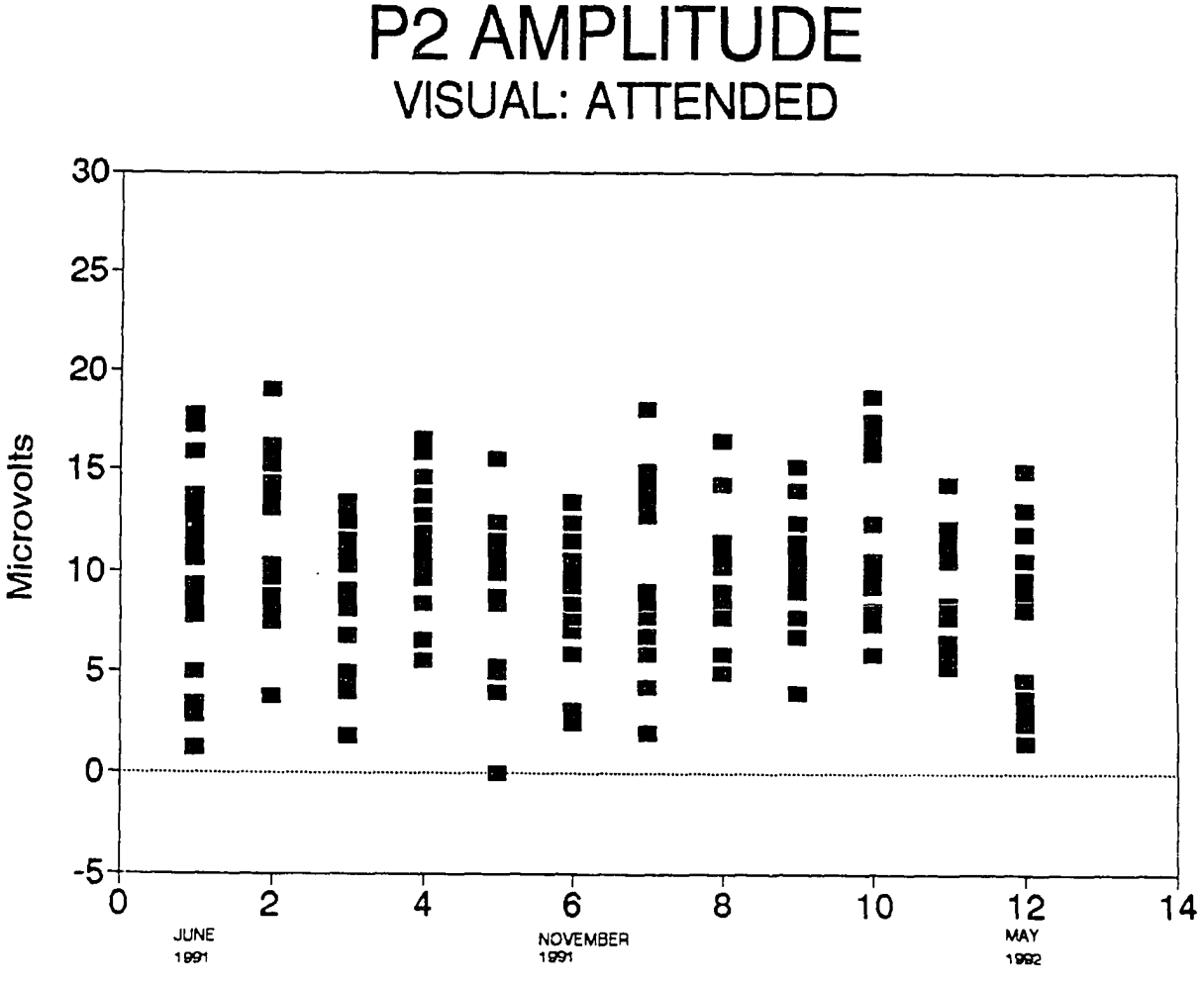


Figure B-14. Variability of the ignored visual P2 amplitude over 12 months.

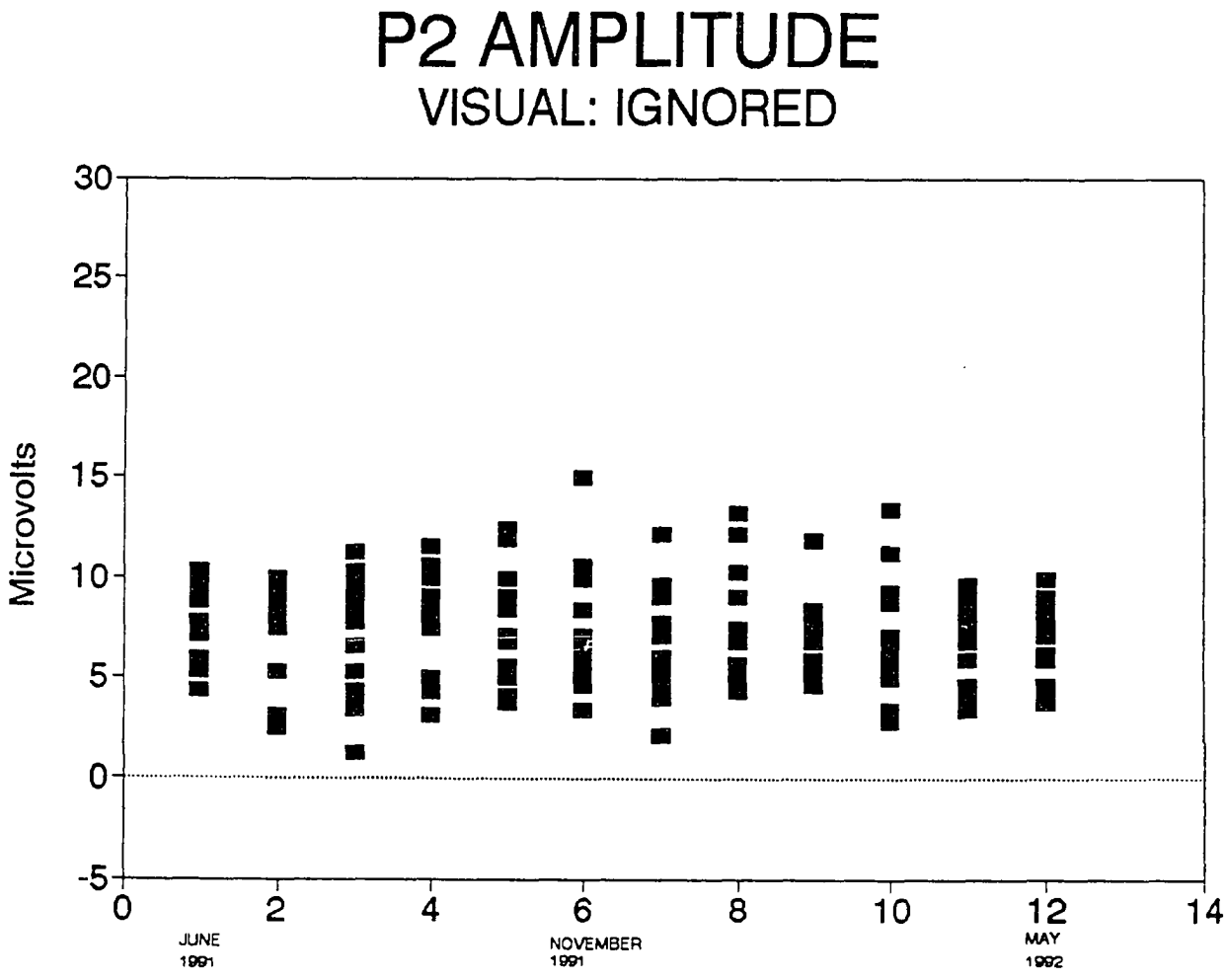


Figure B-15. Variability of the attended auditory P2 latency over 12 months.

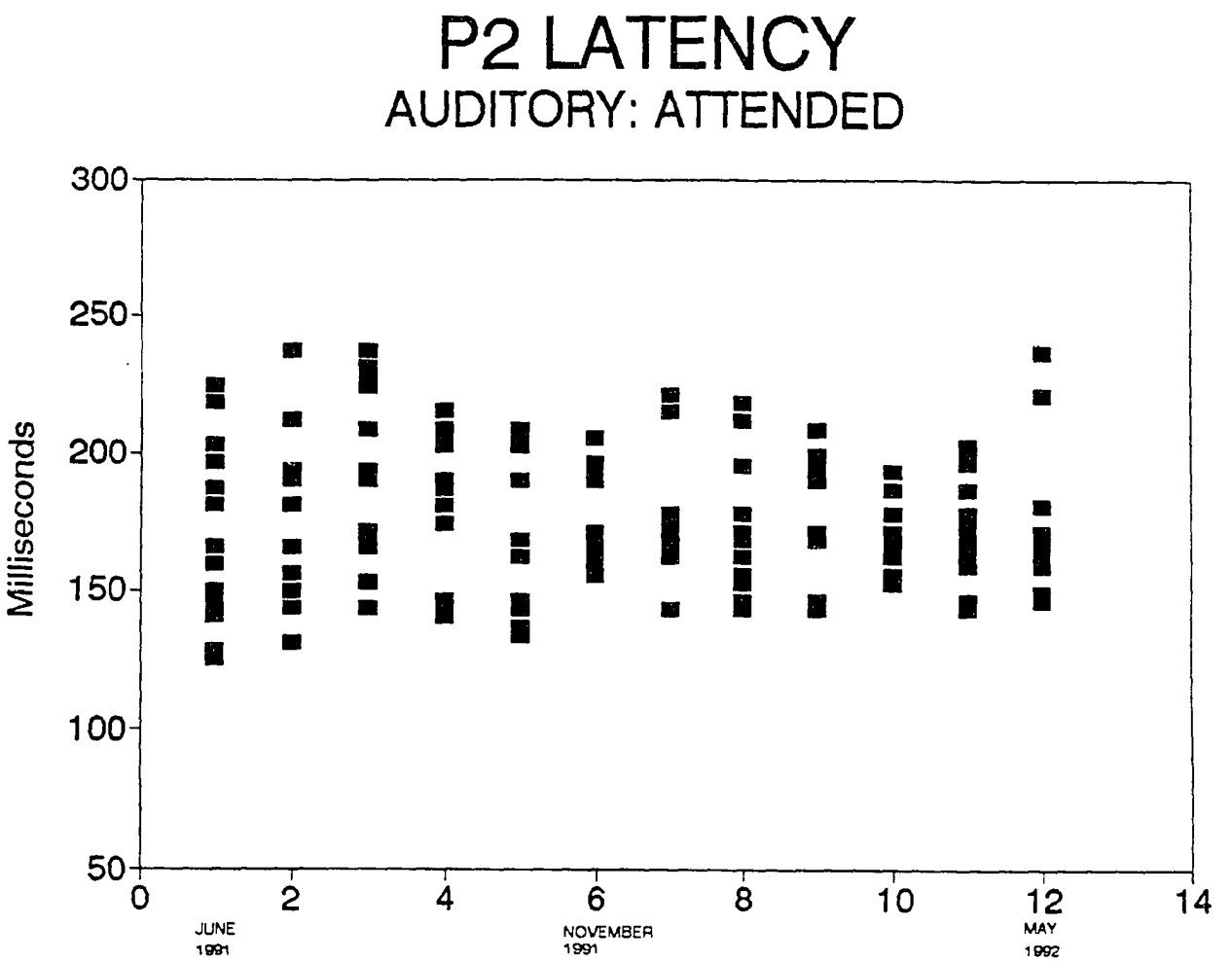


Figure B-16. Variability of the ignored auditory P2 latency over 12 months.

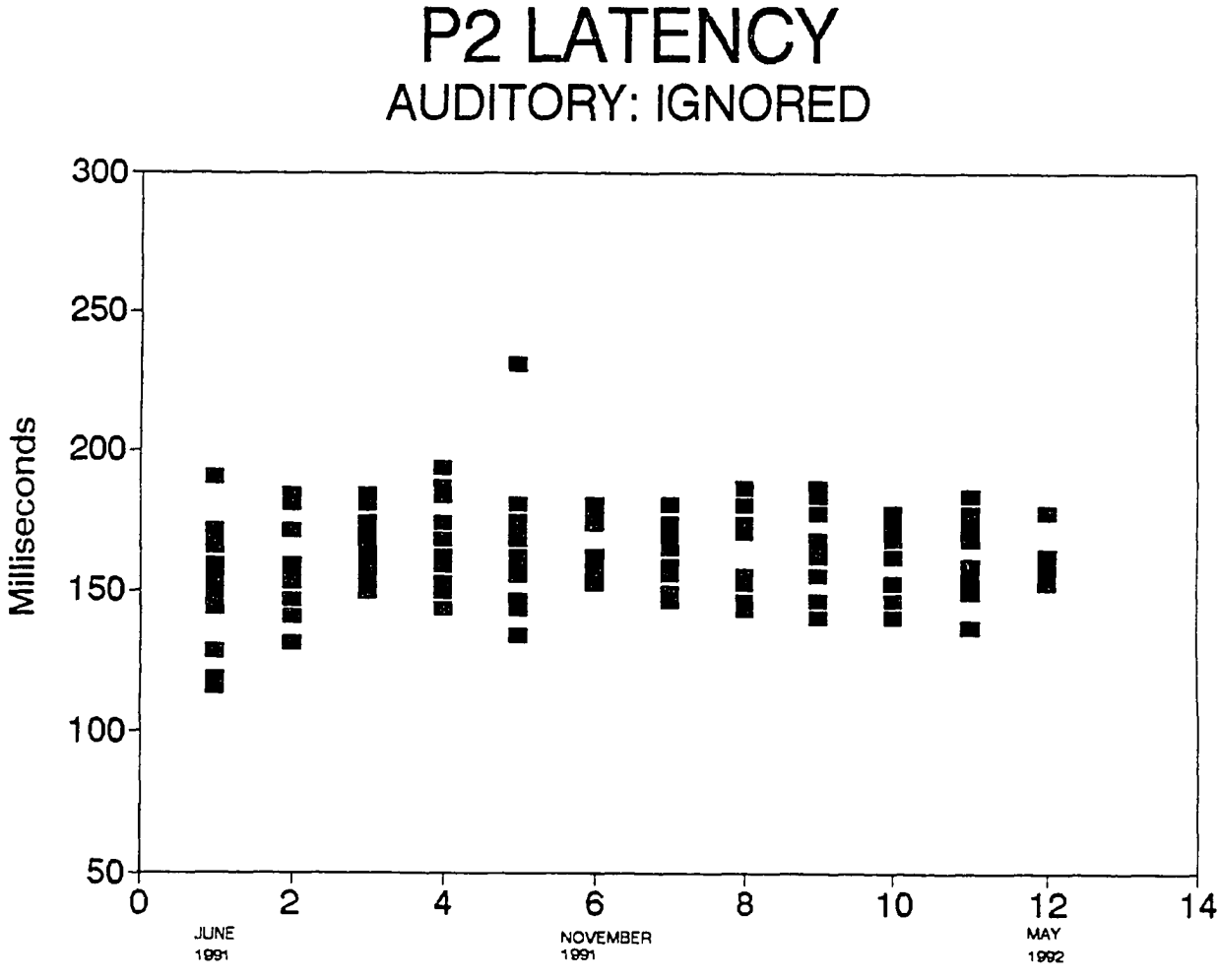


Figure B-17. Variability of the attended visual P2 latency over 12 months.

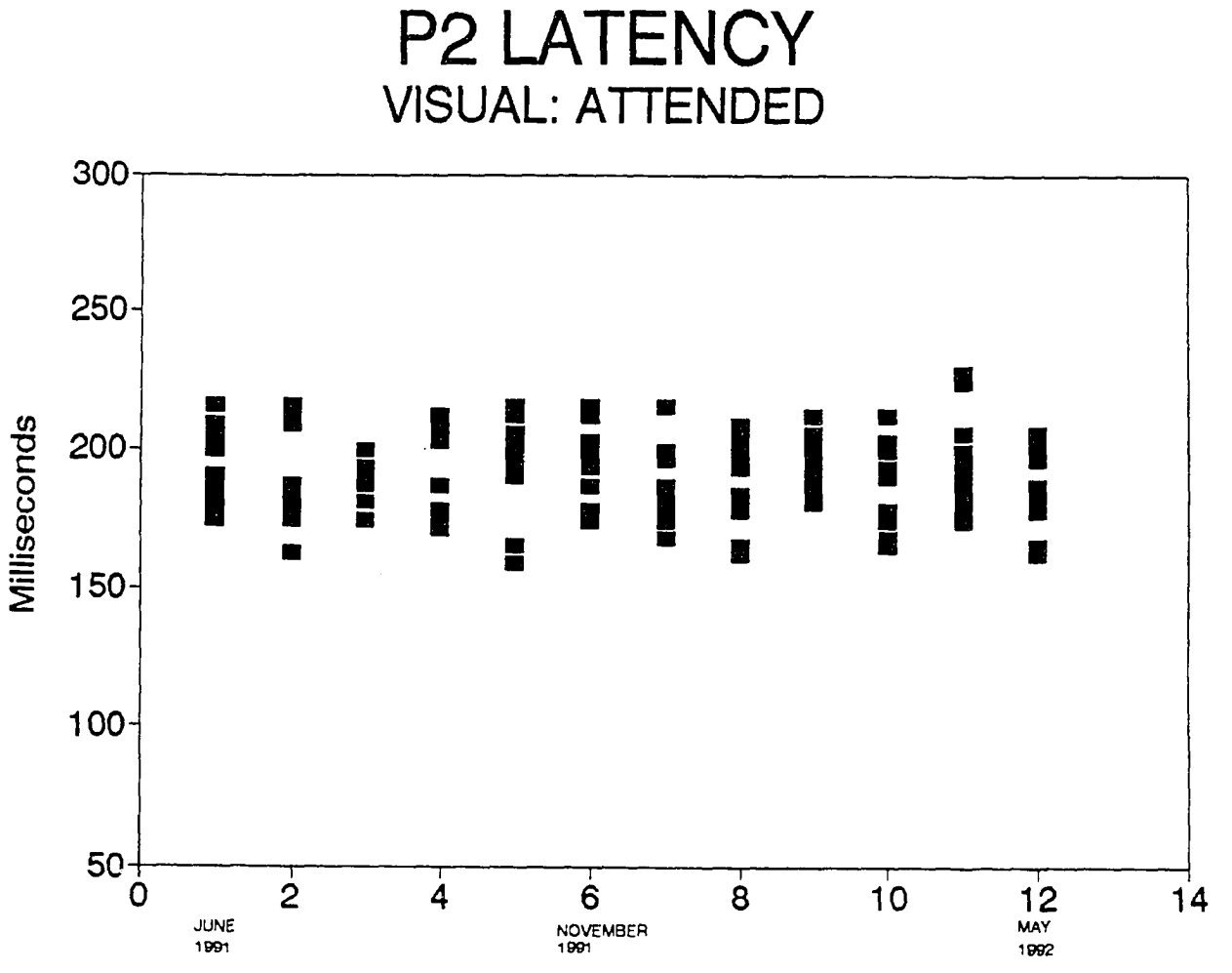


Figure B-18. Variability of the ignored visual P2 latency over 12 months.

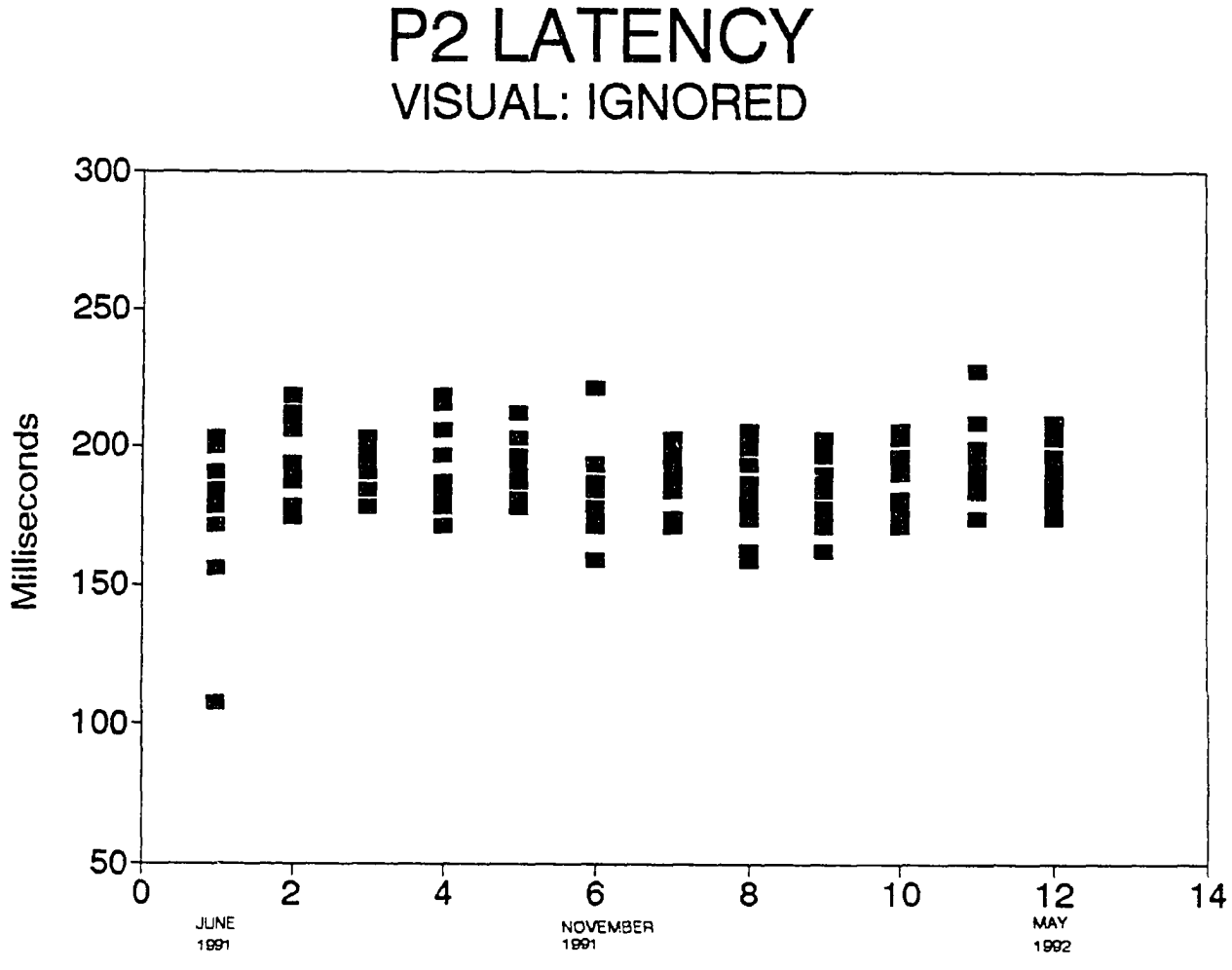


Figure B-19. Variability of the ignored auditory P3 amplitude over 12 months.

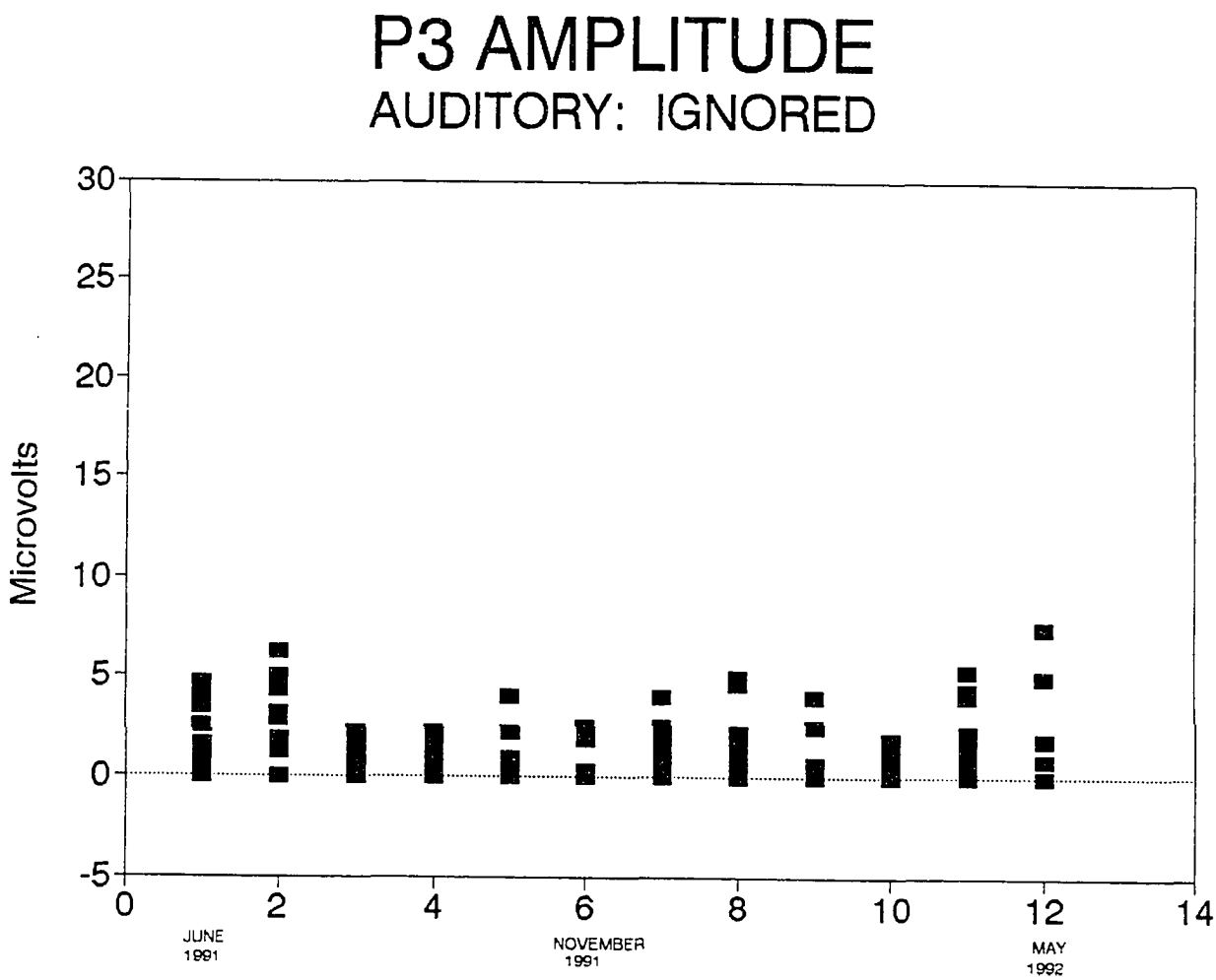


Figure B-20. Variability of the ignored visual P3 amplitude over 12 months.

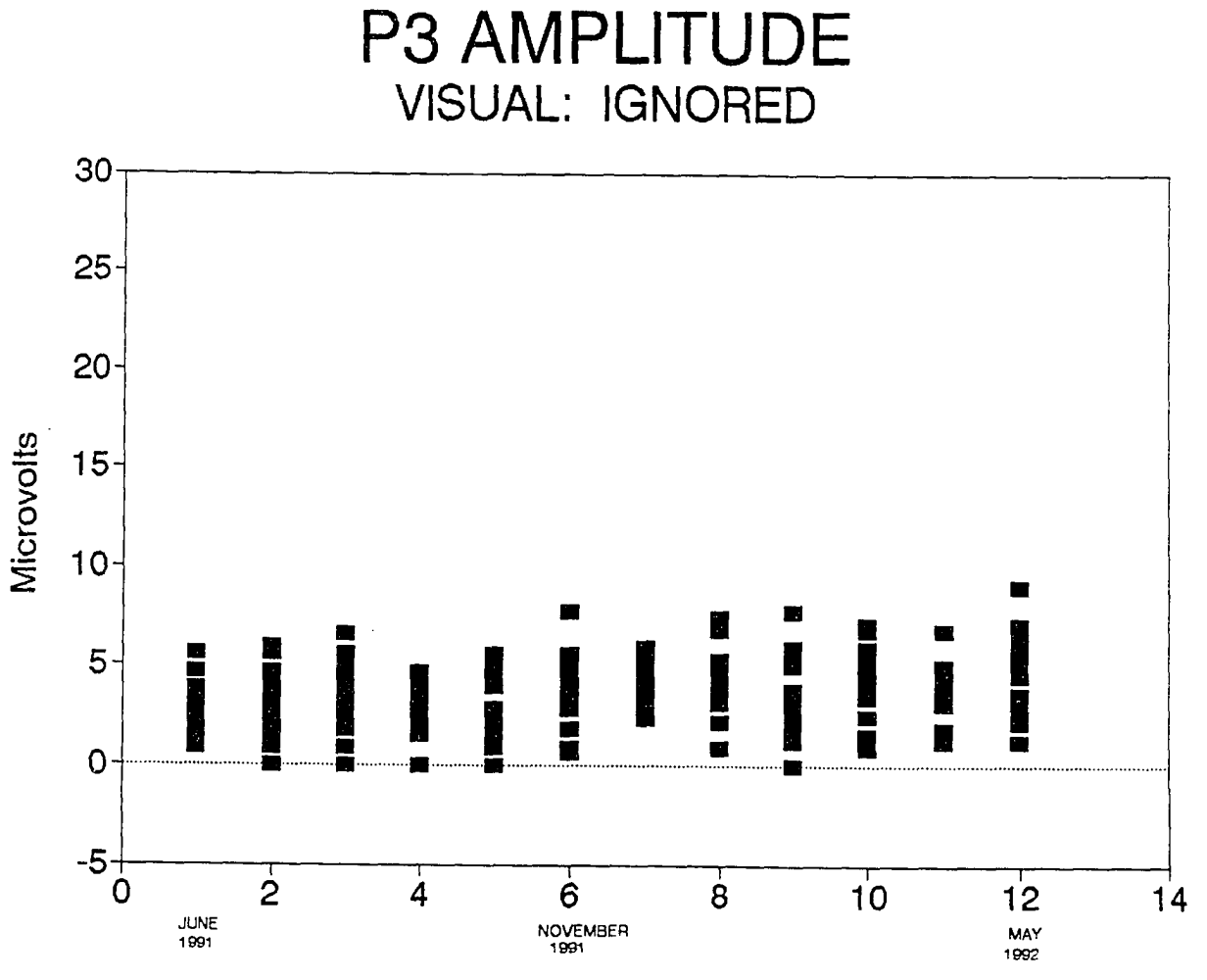


Figure B-21. Variability of the ignored auditory P3 latency over 12 months.

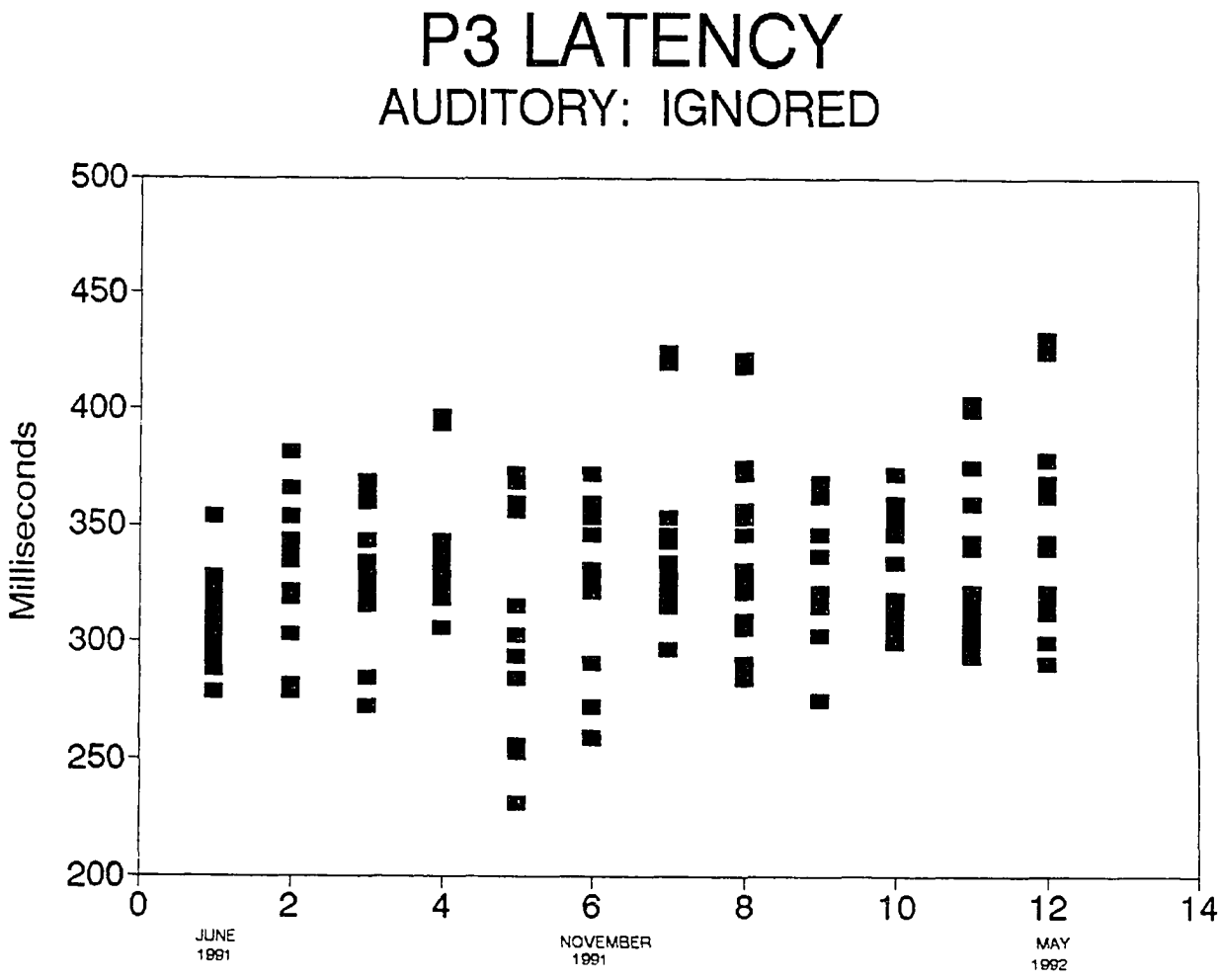


Figure B-22. Variability of the ignored visual P3 latency over 12 months.

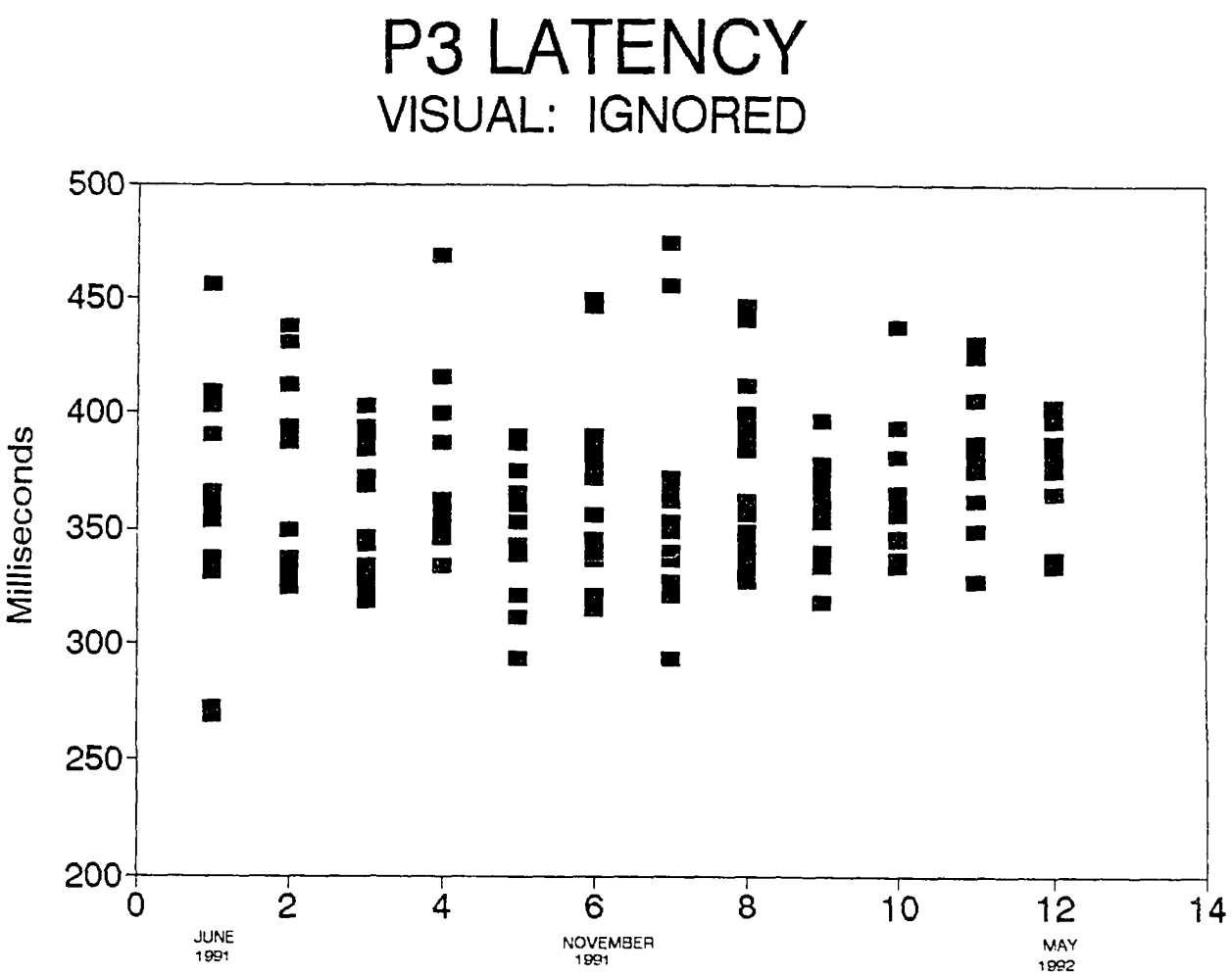
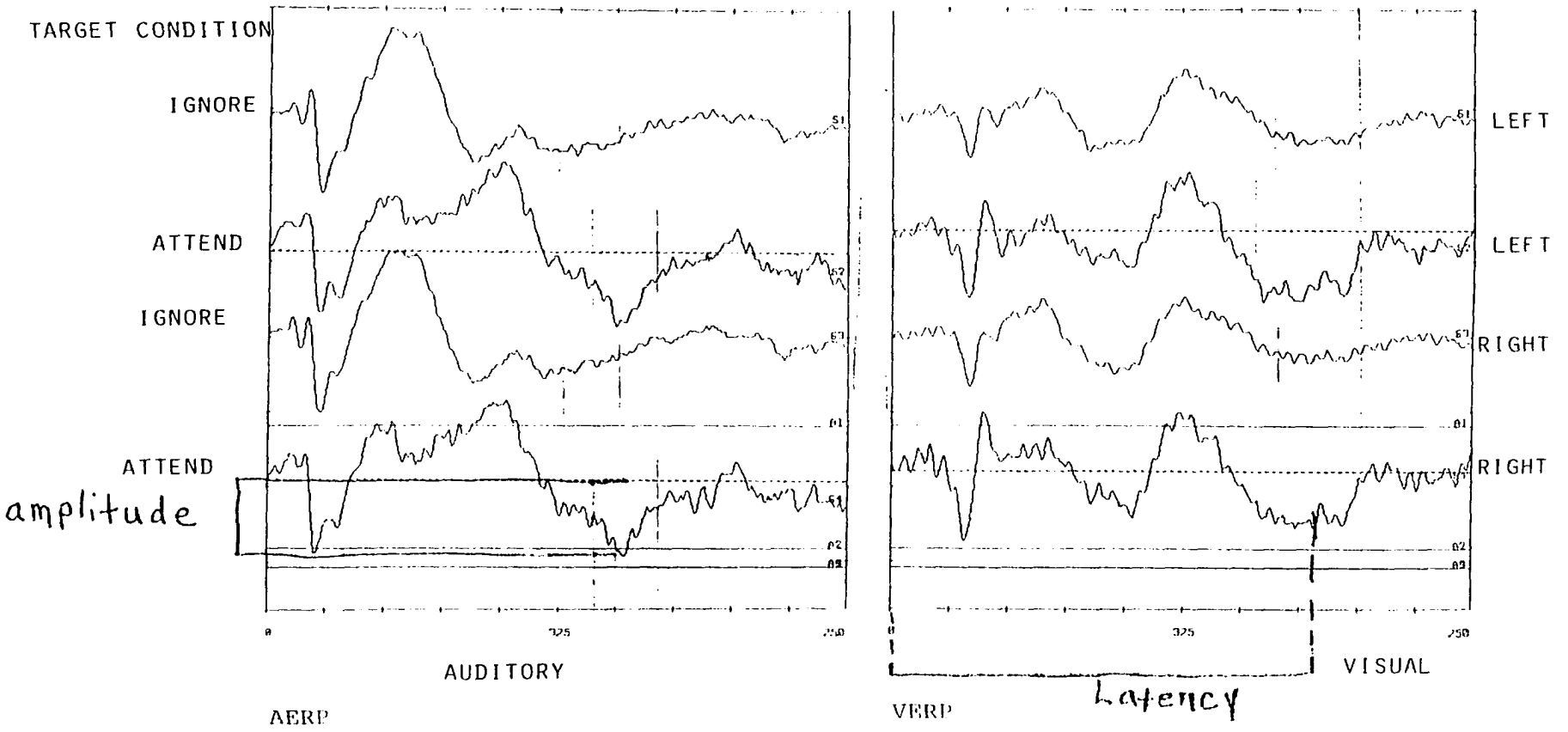


Figure B-23. N4 portion of the ERPs.




N4

Figure B-24. Variability of the attended auditory N4 amplitude over 12 months.

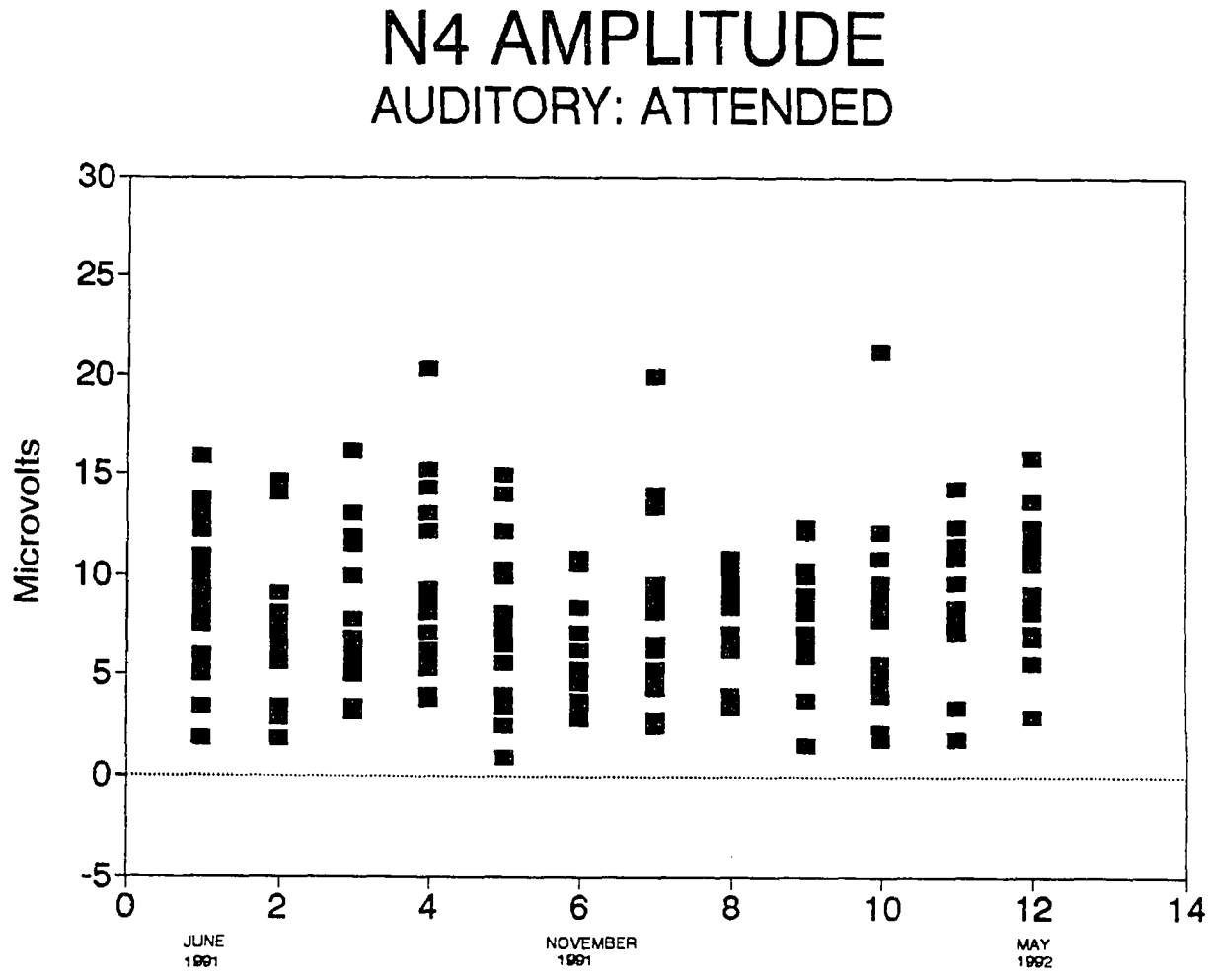


Figure B-25. Variability of the ignored auditory N4 amplitude over 12 months.

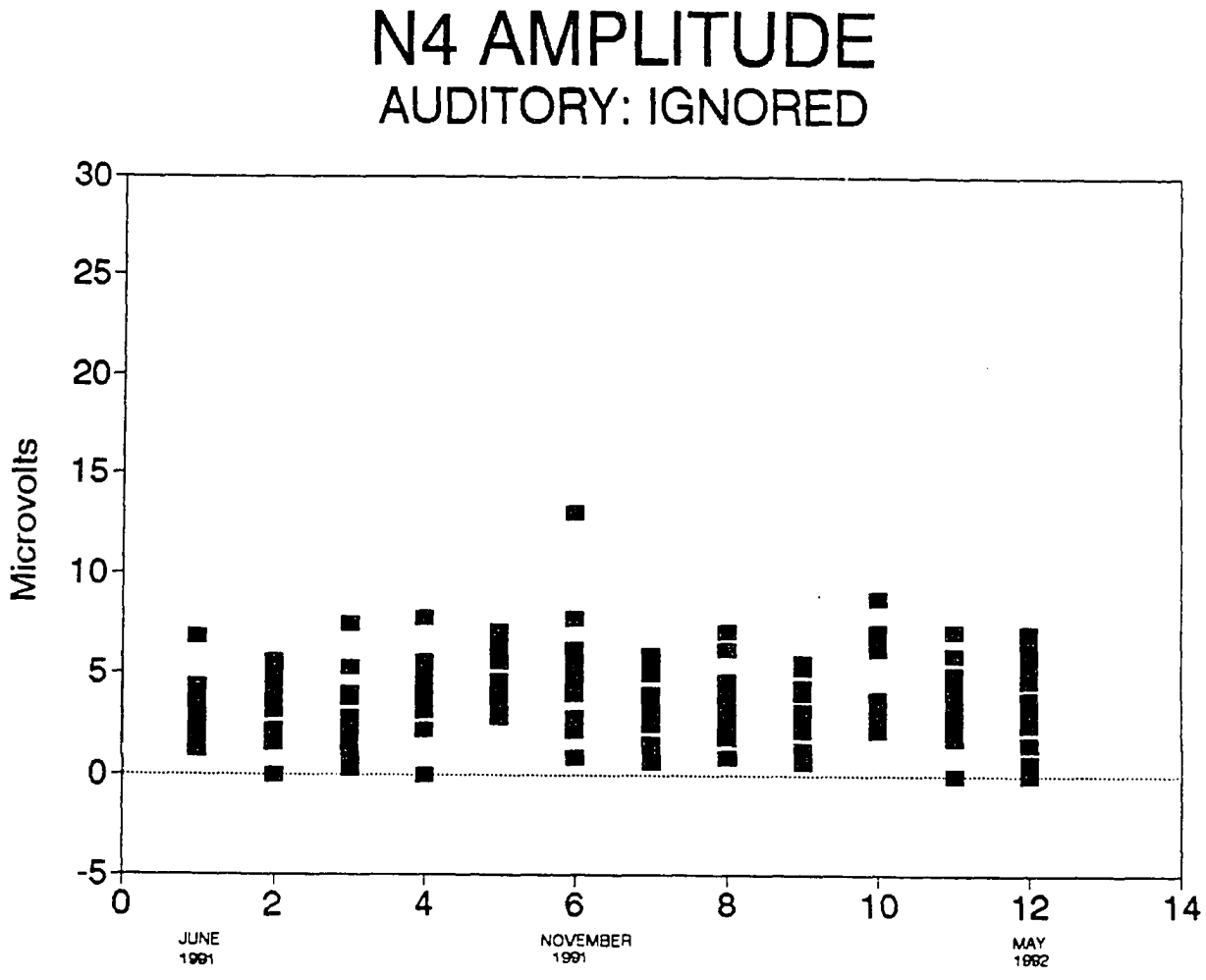


Figure B-26. Variability of the attended visual N4 amplitude over 12 months.

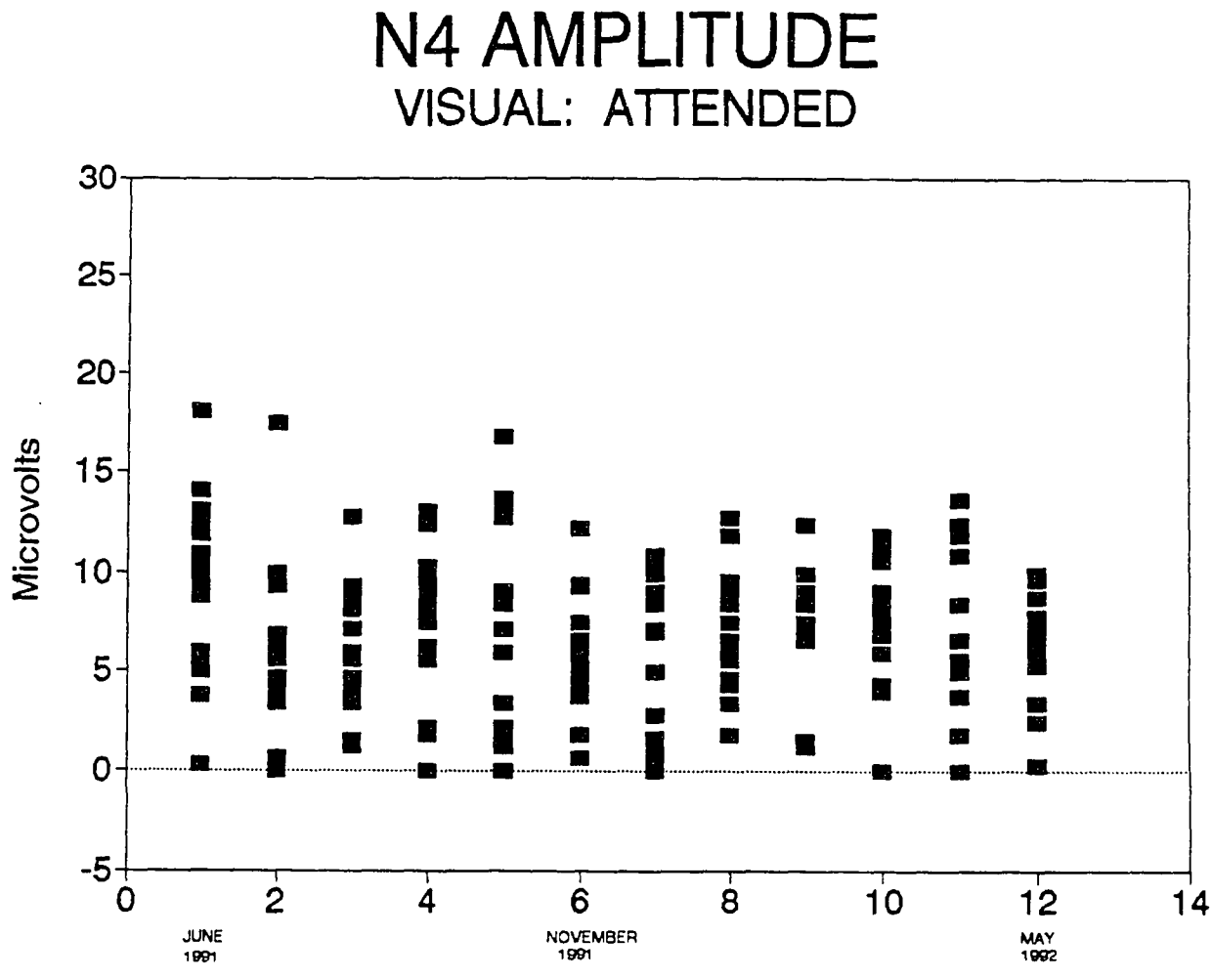


Figure B-27. Variability of the ignored visual N4 amplitude over 12 months.

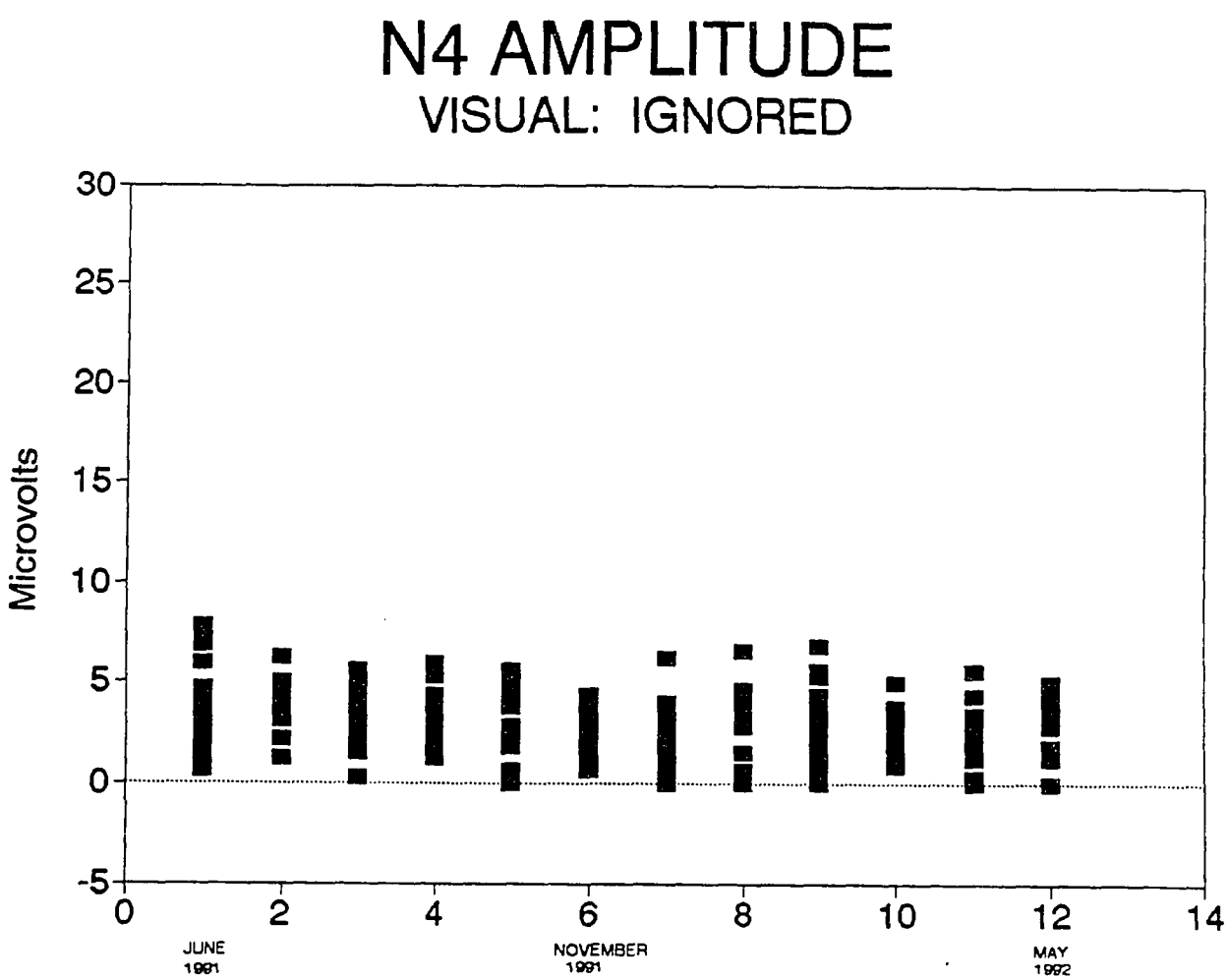


Figure B-28. Variability of the attended auditory N4 latency over 12 months.

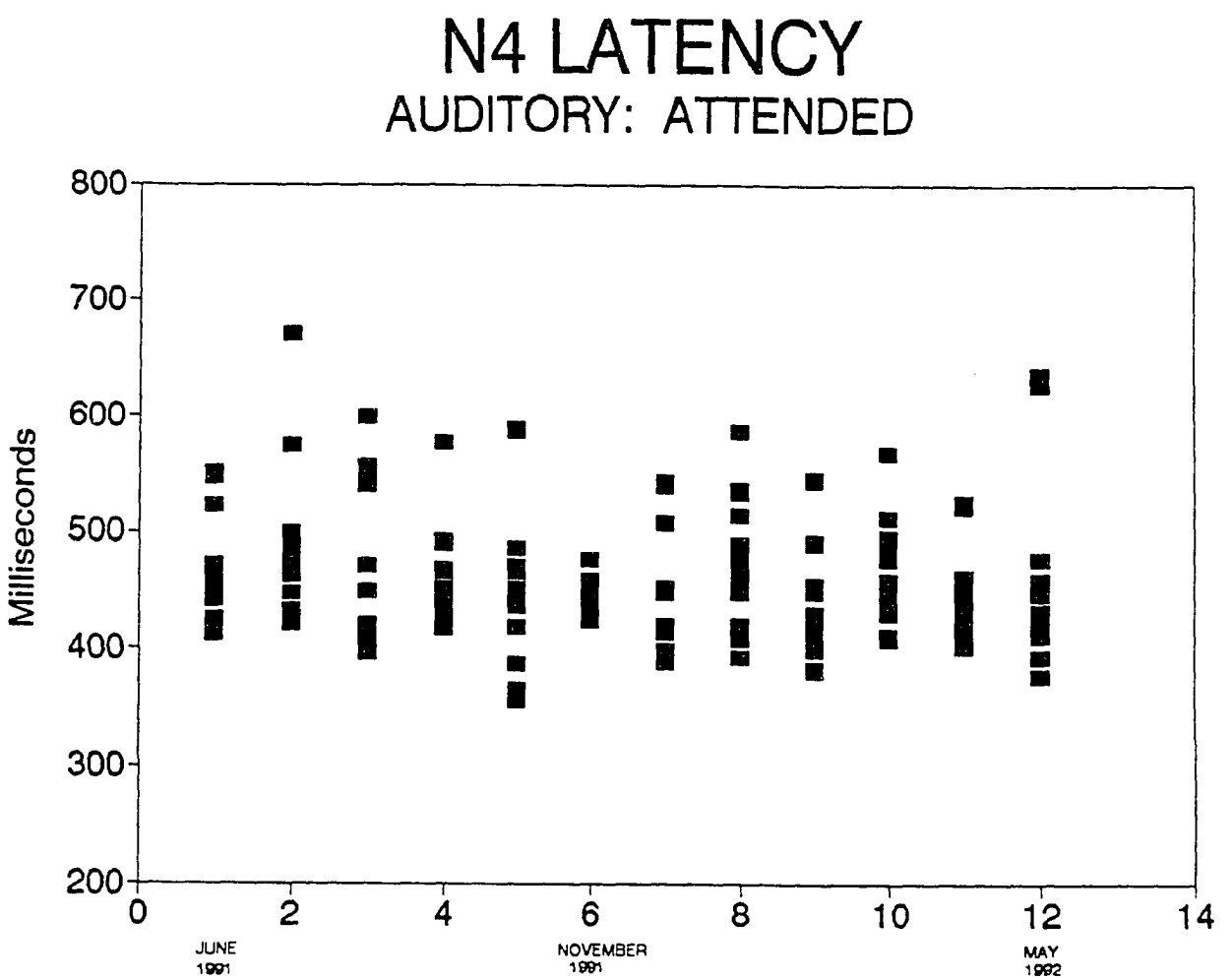


Figure B-29. Variability of the ignored auditory N4 latency over 12 months.

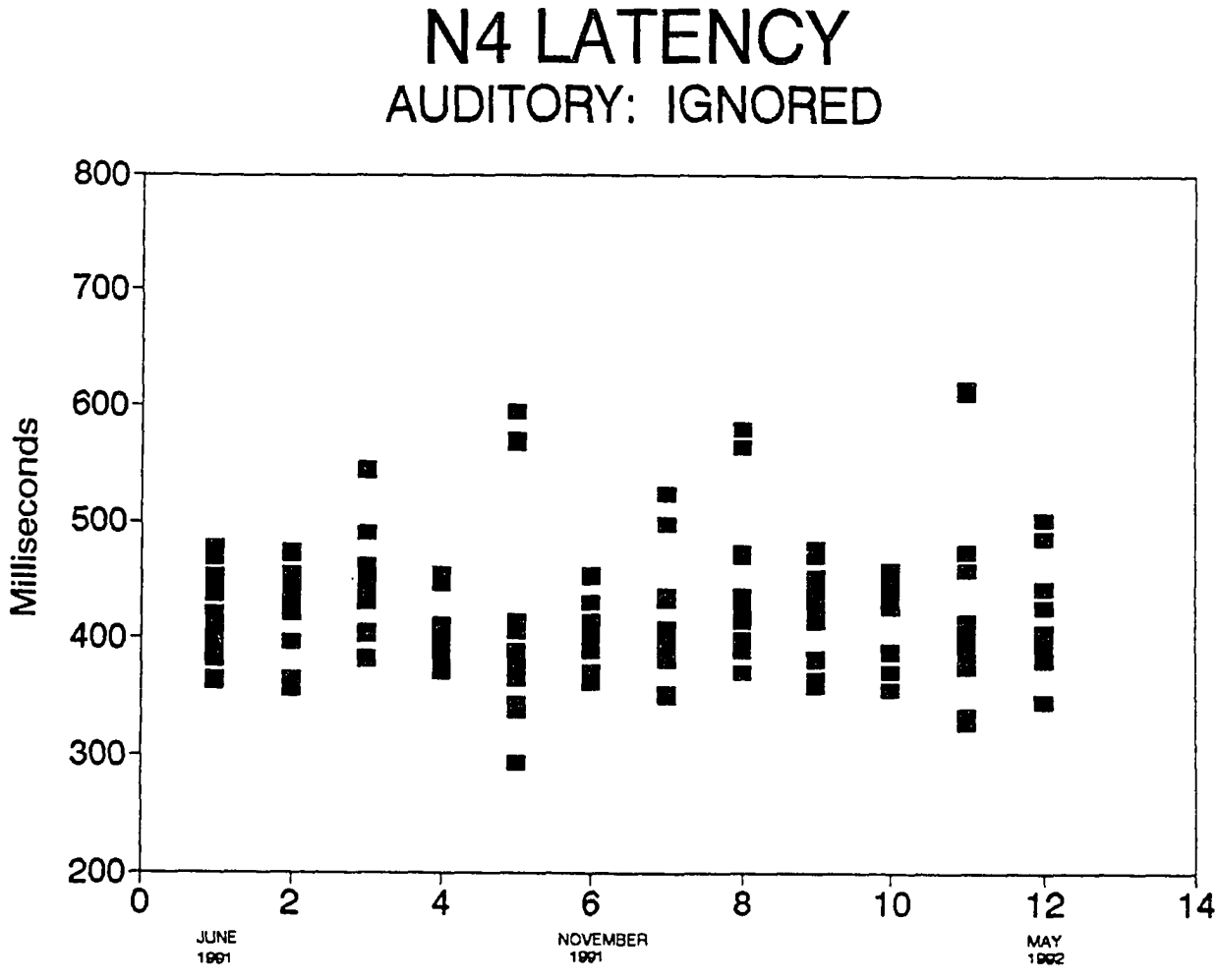


Figure B-30. Variability of the attended visual N4 latency over 12 months.

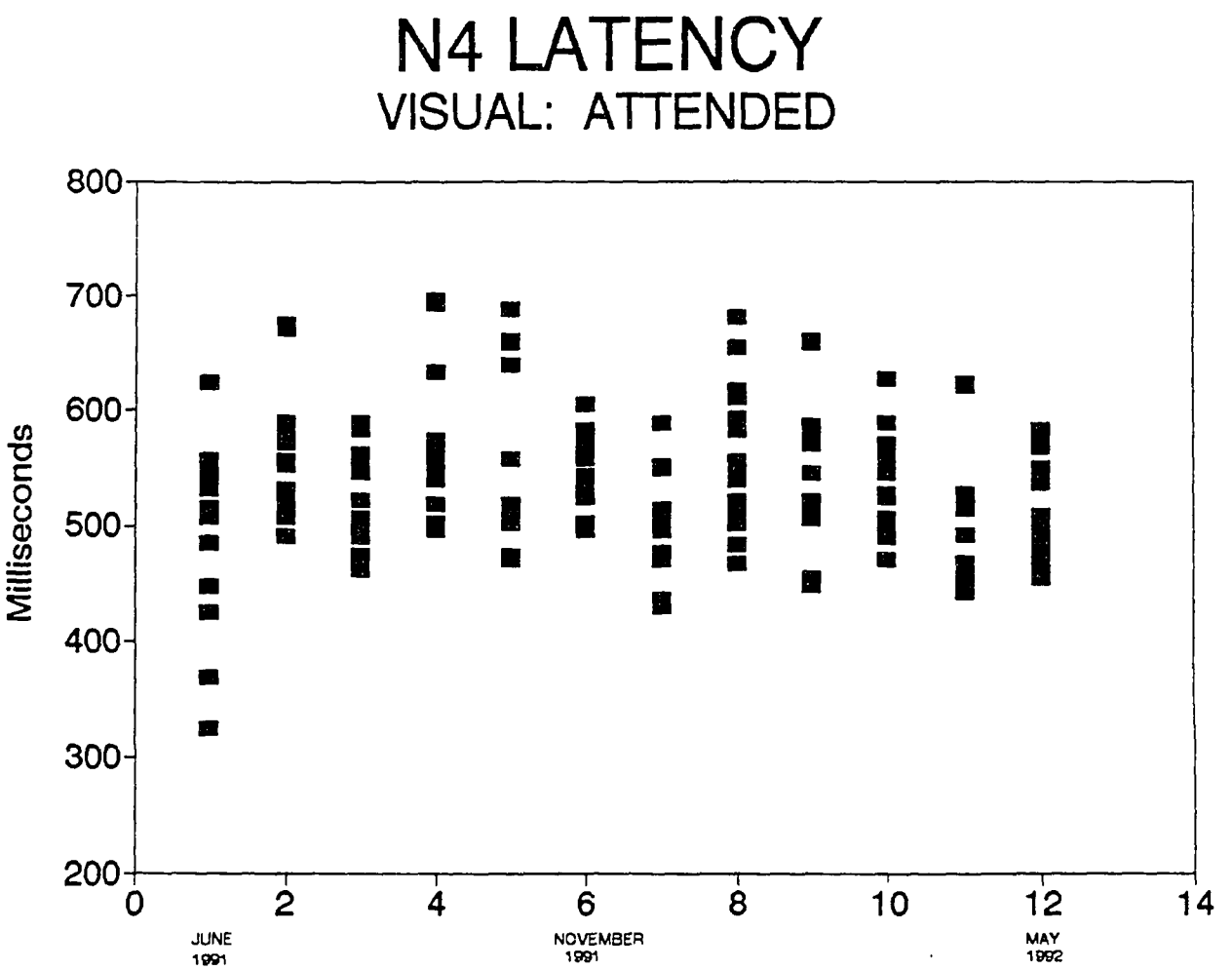


Figure B-31. Variability of the ignored visual N4 latency over 12 months.